Chapter 9

Urban forest carbon sequestration: *Quo Vadis*?

Introduction

The monetary budgets available for urban forestry have declined over the past few years in the City of Tshwane (personal communication: B. Dry, Deputy Manager: Urban Forestry, Nursery and Training of the City of Tshwane Metropolitan Municipality, 2004). According to Mr Dry urban forestry is not viewed as a priority public service but rather as an aesthetic attribute of the city and is hence allocated less funds. It is the author's impression when discussing urban forestry monetary budgets with municipal officials that this is a common situation in South Africa and that there is a general despondency about this trend and even desperation for the acknowledgement of the importance of the urban forest as an integral part of the city's urban infrastructure. Few officials furthermore, have verification of the value that urban forests hold in a local context to be able to motivate larger budgets. The results presented in Chapter 6 and Chapter 7 have been an attempt at illustrating the importance of the urban forest as part of a city's infrastructure by quantifying the carbon stored in the trees in monetary terms. However, carbon sequestrated by past and recently established urban forests do not qualify for actual carbon trade. Hence, the following is a brief discussion as to possible carbon baselines, business as usual practices and leakages that need to be considered in carbon accounting for actual trading of the carbon stored in current and new urban forests. The concept of additionality is also discussed in order to provide some possible solutions to obtain tangible urban forest carbon monetary benefits.

Baselines and business as usual practice

A baseline is defined by the Intergovernmental Panel on Climate Change (IPCC 2000) as: "… a reference scenario against which a change in greenhouse gas emissions or removals is measured." Baselines are thus the point of departure from which carbon debits or credits are calculated. The baseline for municipal urban tree planting could be taken at a specific stage since 1990, which is the Kyoto Protocol cut off date. It is crucial to determine the baseline if Municipalities desire to become carbon accountable.

Municipal tree planting baselines should, however, also be viewed in terms of business as usual practices. In this case the business as usual practice would be the continuation of tree planting which would have taken place regardless of climate change and the Kyoto Protocol. Business as usual practice is not eligible for carbon credits since it does not provide additionalities (see below). However, even though business as usual tree planting practices are viewed as non-credit situations, it still provides an opportunity for calculating the carbon value of the urban forest as has been done in this thesis. Carbon sequestration values of urban trees could be used as motivation for funding for increased tree planting by illustrating the value that these trees hold for urban and global societies.

Leakage

Urban forest and street tree leakages

Emissions related to urban forestry tree planting programmes may in some instances be viewed as greenhouse gas "leakages". A leakage relating to *natural* *forests* and *plantations* is defined as "… the *indirect* impact that a targeted land-use, land-use change and forestry activity in a certain place at a certain time has on carbon storage at another place or time" and also as "… *unanticipated* decrease or increase in greenhouse gas benefits outside of the project's accounting boundary … as a result of project activities" (IPCC 2000; Schwarze *et al*., 2002). In many instances urban forestry management practices have been well established and therefore the emissions resulting from an urban forestry project are not to be perceived as leakages, but rather as project debits that need to be incorporated into the initial project proposal. Schwarze *et al*. (2002) do, however, identify an alternative type of leakage, which he refers to as a "*life-cycle emissions shifting leakage*". They define it as mitigation activities (such as reforestation) that increase emissions in upstream or downstream activities of a forestry project, for example, a reforestation project in a rural setting that increases the use and operation of machinery, which results in fossil fuel emissions (Schwarze *et al*., 2002).

The concept of life-cycle emission shifting leakages may also be applicable to urban forestry and street trees. The urban forestry and urban sprawl leakages mentioned below should be viewed as a part of this broader scope of the term. The term leakage as such has not previously been applied to the urban forest or street tree setting and the leakages mentioned below are thus debateable and open for discussion. They are also not an exhaustive list and do not necessarily fit the use of the term leakages as applied to a conventional natural forest and plantation context. This is an attempt to apply the term to urban forestry and particularly to a street tree context and it is acknowledged that this application may prove to be contentious. It is, however, of paramount importance to identify possible urban forestry leakages so that holistic carbon accounting can be done and that a project may thence be considered for carbon emission reduction certification by the CDM (Clean Development Mechanism).

There are numerous possible carbon leakages relating to tree planting and maintenance. Carbon dioxide emissions from fuel in cultivation, tree planting and maintenance (wood chippers, transportation) are examples. There are other carbon emissions as well: tree branches that are pruned, inevitable tree felling due to pests, wind or disease damage and tree removal by private land owners currently result in carbon dioxide emissions due to decomposition and are hence street tree carbon leakages. There are street tree database inaccuracies as was shown in the Chapter 7. The loss of street trees, which are not accounted for in the Municipal database, could also be viewed as a leakage.

Nitrous oxide (N_2O) is a non-carbon greenhouse gas, which is released with the application of fertilisers. The use of fertilisers in the propagation, cultivation and planting of urban trees could thus also be seen as possible greenhouse gas emission leakage.

Tree and other vegetation waste that accumulate on landfill sites may cause increased methane (greenhouse gas) production at these sites (IPCC 2000). This possible leakage may be reduced by improving the life span of trees as well as by utilising the biomass for other purposes.

Emission leakages need to be accounted for to obtain the complete carbon stock of urban forest or tree-planting projects. The above and other possible leakages should be anticipated and leakage projections should be made when making carbon sequestration projections especially for new tree planting projects. These possible urban forest leakages were not part of this study but need to be addressed in order to obtain complete carbon accounting.

Current carbon leakage emissions emerging from current and past urban forestry establishment and maintenance are, however, not seen as carbon debit but rather as business as usual carbon emission practices. Municipalities could hence not be debited for these business as usual leakages. However, should these leakages be reduced due to other forest management practices then the reduced emission may be seen as additionality and may possibly be a carbon credit.

Urban sprawl leakage

Urban sprawl needs to be considered when viewing the City of Tshwane as well as South Africa in a broader potential urban vegetation carbon emission leakage perspective. Sprawl has increased due to governmental commitment to the provision of housing to the previously disadvantaged. What needs to be considered is that during the construction of the houses the stands are mostly denuded of vegetation, this results in carbon debits. Currently, neither the government, whether national, provincial or local, nor the landowner are being held responsible for the deforestation and vegetation clearing which results in carbon releases and increases the effects of global warming. Accountability for this carbon emission is necessary.

Conversely some of these housing areas are re-vegetated. Again no ownership is taken for the carbon sequestration taking place with urban tree planting and urban greening. Ownership may be viewed positively since it may produce tradable carbon credits, which may in turn aid these communities and motivate further urban tree planting. Government policy needs to be drafted in order to firstly obtain the credits and secondly to allocate them to the rightful recipients.

The east of Tshwane underwent severe urban sprawl with low-cost housing, as well as higher density and high-income housing developments. Based on visual observation areas with low income housing typically stay denuded of vegetation post construction and therefore remains at least for some time in a carbon debit situation. Tree planting may alter this debit. Higher density developments for example two-story cluster housing are possibly also built and maintained at a carbon loss when only considering pre - and post - construction vegetation. This is due to the small spaces available for greening and tree planting in these developments. They will probably remain in this carbon debit state. Some high-income residential developments in the east of Tshwane are developments with large stands and golf course estates. Due to intense landscaping these areas are possibly carbon neutral or in a carbon benefit situation. It is re-emphasized that accountability for land clearing in urban developments is necessary.

Additionality

An "additionality" would be a prerequisite to incur urban forestry carbon credits (IPCC 2000) and certified emission reductions (CERs). Additionality is the issue of whether a forestry action enables more carbon storage than would have been stored without a specific human intervention (Scholes 2004). A policy was adopted to limit the CDM forestry projects for the first commitment period (2008 – 2012) to reforestation and afforestation projects only (UNFCCC 2001; Brown *et al*. 2002). In the view of Municipal tree planting budget cuts it is unlikely that many municipalities will be able to obtain additionality through additional afforestation and reforestation. Additional afforestation and reforestation may also be regarded as part of business as usual practice of a municipality. In the discussion below suggestions as to possible additionalities that may be taken into consideration are made. These suggestions are derived from a local South African environment and are open for discussion and it is hoped that they will fuel the debate. The term is, however, applied broadly to an urban forestry context. As yet, current and future CDM additionality in terms of alternative urban forest management practice have not been defined. The urban forest management practices suggested below, although not exhaustive, may potentially be incorporated in the consideration of urban forestry additionality for the next commitment period. It should furthermore be mentioned that alternative forest management practice additionality, although not necessarily approved by the CDM for the current commitment period, may be acceptable for trade to, for example, the World Bank's Bio Carbon Fund without prior emission reduction certification.

An example of alternative forest management practice is to use pruned branches and felled trees as structural timber in previously disadvantaged communities. The wood could also be harvested and used in furniture and curio industries. This will lengthen the carbon storage time because the wood will not decompose as speedily than had it been chipped and used as mulch. Harvestable wood products could be viewed as a beneficial additionality. However, product life cycle assessment may be complex.

If the wood of pruned and felled trees is used as biofuel for cooking and heating purposes it could also be viewed as reducing the use of fossil fuels like paraffin and coal and could hence be seen as a reduction in the latters' emissions and could thus result in additionality. Furthermore, converting biomass to energy may reduce the need for landfill space and reduce methane emissions from landfill sites (IPCC 2000) Economic benefits from the biomass energy conversion may offset the costs (IPCC 2000).

Prolonging the lifespan of trees and improving urban tree growth rates may also ensure additionality due to more carbon being sequestrated for longer time periods (IPCC 2000). These two aims could be achieved through improving urban forest maintenance and management practices.

Tree maintenance additionality could perhaps also be reached through alternative street tree pruning practices. If, for example, less power equipment is used and is replaced by conventional manpower then less fuel will be used resulting in a possible additionality. This option will also result in work creation. Furthermore if pruning cycles could be lengthened to two or three year cycles instead of business as usual annual cycles then possible additionality may also be reached through the reduction in use of fossil fuel.

A further potential and possible option to attain additionality is making use of non-government tree planting organisations like, for example, Food and Trees For Africa (FTFA). Currently FTFA focuses its tree planting programmes on new housing developments of previously disadvantaged communities. The backlog of tree planting in the older and established Townships is, however, the main focus of the Municipality. FTFA could possibly be granted permission or be requested to supplement current tree planting for these Township areas. FTFA may in turn obtain carbon credits for the trees planted because the extra trees planted may be regarded as an additionality. This is because the trees would not have been planted had an alternative forest management policy not been adopted by the Municipality and because additional trees, to that of the business as usual scenario, will be planted. It can be a condition that the proceeds from carbon credit additionality trade will be used for further urban forestry. Further tree planting once again starts the cycle of tree planting, incurring additionality and carbon trade, which will result in further trees being planted, and the cycle repeats itself. This opportunity will become even more lucrative if the Municipality accept responsibility for maintenance of the trees, which will incur carbon debits due to maintenance practices to the Municipality and result in maximum availability of carbon additionality credits for FTFA. It is suggested that potential urban forest additionalities be made a research priority so that urban tree planting may advance at a more rapid rate.

Conclusion

Urban forest carbon sequestration research is currently one of the most important fields of urban forestry research. This is because of the fact that global warming is the single most devastating threat to biodiversity and indeed life on earth as we currently know it and urban forestry carbon sequestration research is thus of global importance. Hence, budget reduction trends and the perception of the relatively low importance of urban forests need to be altered and it probably cannot be changed by research and results based on urban carbon sequestration findings alone. Other urban forest benefits as mentioned in the previous chapters also need to be researched to complement carbon sequestration research. This is necessary so that all aspects of the attributes of urban forests could be used for the motivation to plant more trees which will hence result in more effective climate amelioration in the urban environment. The potential devastating threat of global warming could thus be addressed, albeit in moderate terms, by urban tree planting, which is motivated by the monetary value of urban forests to South African communities and especially previously disadvantaged communities. The urban forestry opportunity in previously disadvantaged communities and Townships will furthermore enable these *non-industrialised*, *poor populations* of a *developing* country to assist in the amelioration of the effects of industrialisation and deforestation on global warming.

References

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Appendix A

The following is a South African patent written in collaboration with a local patent law firm. The patent was based on the research done for this thesis.

The patent reads as follows:

THIS INVENTION relates to ecological management. In particular, the invention provides a method of ameliorating the ecological effects of carbon emissions. The invention also relates to a system for calculating the quantity of carbon sequestered by a tree over a predetermined time period. The invention further extends to carbon credits for offsetting carbon emissions.

The invention provides a method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem circumference *(c)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$c_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

c_i	=	the estimated value of the stem circumference of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

and by using a value for *A* of 4.44032 - 4.72672, a value for *b* of 2.17927 - 2.70242, and a value for *MSE* of 0.11467 - 0.19853.

The stem circumference *(c)* is preferably estimated by using a point value for *A* of 4.58352, a point value for *b* of 2.44085, and a point value for *MSE* of 0.14804.

The method defined above is typically used when the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Combretum erythrophyllum*. It should be appreciated, though, that the abovementioned values and equation could also be applied to trees of other species. In particular, the values given below for use in respect of trees of various associated species can be used for any tree which has a sufficiently similar size for such application to be made with botanical assurance.

By the natural logarithm is meant $\log_e$, also referred to as ln.

It will be appreciated that trees assimilate atmospheric carbon during their growth process. To curb carbon emissions, which serve to increase the atmospheric carbon concentration and contribute to global warming, industrially active entities may be set limits as to the quantity of carbon they are allowed to emit. Application of the method enables such entities to exercise the option of buying carbon credits in respect of trees which have been planted by themselves or by others, thus increasing the quantity of carbon which that entity may emit by the quantity of carbon sequestered by the associated trees.

It should further be appreciated that the carbon credits relate to a predetermined time period, and that the quantity of carbon offset by the carbon credits is equal to the quantity of carbon sequestered by the associated trees over the predetermined period. If the predetermined period starts at planting of the trees, calculation of the quantity of carbon sequestered by the trees at the end of the period will provide the quantity of carbon emissions which the carbon credits permit. Otherwise, the quantity of carbon sequestered by the trees at the start of the period is subtracted from the quantity of carbon sequestered at the end of the period, to provide the total quantity of carbon sequestered by the trees in the predetermined period.

Stem circumference or stem diameter at ground level implies a measurement taken at 0 - 20 cm above the ground or appropriately measured above the basal swelling. Furthermore, the basic equation and associated values of *A*, *b* and *MSE* are intended for use in respect of trees having an age of up to about thirty years, with the accuracy of the equation declining for trees above that age. For trees of the species *Combretum Erythrophyllum*, the given equations are accurate up to an age of about 47 years, while the equations are accurate in respect of *Rhus lancea* up to 32 years and up to 15 years for *Rhus pendulina*.

The above equation implies a relationship between appropriately paired values of tree age and the stem circumference of a plurality of trees. By use of pre-estimated point values for *A*, *b* and *MSE*, an estimated stem circumference *(c)* for one of the trees can be found. It should be appreciated that the stem circumference which is estimated in this way represents the stem circumference of a tree which is statistically representative of the plurality of trees. This representative tree is referred to in the above equation as the i^{th} tree. In other embodiments of the invention, which are defined below, there is provided equations which describe a relationship between appropriately paired values of tree age and stem diameter.

The point values for *A*, *b*, and *MSE* are statistically the best estimates to use in estimating the stem circumference or stem diameter, as the case may be, of one of the plurality of trees, while the ranges of values for *A*, *b*, and *MSE* represent the 95% confidence intervals for each. It will be appreciated that the values of *A*, *b*, and *MSE* vary for different tree species. This applies also to the point values and to the value ranges for use in respect of the respective tree species.

The invention extends to a method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem circumference *(c)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$c_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln\left(\ln\left(x_i + 1\right)\right)\right)\right\}$$

where:

c_i	=	the estimated value of the stem circumference of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

and by using a value for *A* of 4.84110 - 5.01122, a value for *b* of 1.60305 - 1.89217, and a value for *MSE* of 0.044657 - 0.076904.

The stem circumference *(c)* may be estimated by using a point value for *A* of 4.92616, a point value for *b* of 1.74761, and a point value for *MSE* of 0.057522. The method defined above is typically used when the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Rhus lancea*.

The invention further provides a method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem circumference *(c)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$c_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

c_i	=	the estimated value of the stem circumference of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

using a value for *A* of 4.32945 - 4.73904, a value for *b* of 1.91382 - 2.51685, and a value for *MSE* of 0.038070 - 0.074931.

The stem circumference *(c)* is preferably estimated by using a point value for *A* of 4.53425, a point value for *b* of 2.21533, and a point value for *MSE* of 0.051892.

The method defined above is typically used when the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Rhus pendulina*.

It may sometimes be necessary to calculate the quantity of carbon sequestered by trees which are not of the species *Combretum erythrophyllum*, *Rhus pendulina*, or *Rhus lancea,* and of which the mean approximate tree size is not sufficiently similar to one of the abovementioned species to justify application of the equation and values for one of said species. In such case, values of *A, b* and *MSE* are used for an appropriate combination of the abovementioned three species.

The invention thus extends to a method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem circumference *(c)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$c_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

c_i	=	the estimated value of the stem circumference of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

using a value for *A* of 4.68409 - 4.85555, a value for *b* of 1.90258 - 2.20418, and a value for *MSE* of 0.093359 - 0.13699.

The stem circumference *(c)* is preferably estimated by using a point value for *A* of 4.76982, a point value for *b* of 2.05338, and a point value for *MSE* of 0.11204.

The method as defined above is typically used when the trees in respect of which the quantity of sequestered carbon is calculated are of a species of indigenous African savannah tree of which the mean approximate tree size lies between the mean approximate tree size of trees of the species *Combretum erythrophyllum* and the mean approximate tree size of trees of the species *Rhus lancea.*

The invention also extends to a method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem circumference *(c)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$c_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

c_i	=	the estimated value of the stem circumference of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

using a value for *A* of 4.79386 - 4.95424, a value for *b* of 1.65237 - 1.90861, and a value for *MSE* of 0.048428 - 0.073722.

The stem circumference *(c)* is typically estimated by using a point value for *A* of 4.87405, a point value for *b* of 1.78049, and a point value for *MSE* of 0.059088.

The method as defined above is typically used when the trees in respect of which the quantity of sequestered carbon is calculated are of a species of indigenous African savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Rhus pendulina* and the mean approximate tree size of trees of the species *Rhus lancea.*

The invention yet further provides a method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem diameter *(d)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$d_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

d_i	=	the estimated value of the stem diameter of the ith tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the ith tree, in years,

and by using a value for *A* of 3.29559 - 3.58199, a value for *b* of 2.17927 - 2.70242, and a value for *MSE* of 0.11467 - 0.19853.

The stem diameter *(d)* is preferably estimated by using a point value for *A* of 3.43879, a point value for *b* of 2.44085, and a point value for *MSE* of 0.14804.

The method defined above is typically used when the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Combretum erythrophyllum*.

The invention also extends to a method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem diameter *(d)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$d_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

d_i	=	the estimated value of the stem diameter of the ith tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the ith tree, in years,

using a value for *A* of 3.69637 - 3.86649, a value for *b* of 1.60305 - 1.89217, and a value for *MSE* of 0.044657 - 0.076904.

The stem diameter *(d)* is preferably estimated by using a point value for *A* of 3.78143, a point value for *b* of 1.74761, and a point value for *MSE* of 0.057522.

The method defined above is typically used when the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Rhus lancea*.

The invention further provides a method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem diameter *(d)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$d_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

d_i	=	the estimated value of the stem diameter of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

and by using a value for *A* of 3.18472 - 3.59431, a value for *b* of 1.91382 - 2.51685, and a value for *MSE* of 0.038070 - 0.074931.

The stem diameter *(d)* is typically estimated by using a point value for *A* of 3.38952, a point value for *b* of 2.21533, and a point value for *MSE* of 0.051892.

The method defined above is typically used when the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Rhus pendulina*.

The invention also provides a method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem diameter *(d)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$d_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

d_i	=	the estimated value of the stem diameter of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

and by using a value for *A* of 3.53936 - 3.71082, a value for *b* of 1.90258 - 2.20418, and a value for *MSE* of 0.093359 - 0.13699.

The stem diameter *(d)* is preferably estimated by using a point value for *A* of 3.62509, a point value for *b* of 2.05338, and a point value for *MSE* of 0.11204.

The method defined above is typically used when the trees in respect of which the quantity of sequestered carbon is calculated are of a species of indigenous African savannah tree of which the mean approximate tree size lies between the mean approximate tree size of trees of the species *Combretum erythrophyllum* and the mean approximate tree size of trees of the species *Rhus lancea.*

The invention extends to a method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem diameter *(d)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$d_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln\left(\ln\left(x_i + 1\right)\right)\right)\right\}$$

where:

d_i	=	the estimated value of the stem diameter of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

and by using a value for *A* of 3.64913 - 3.80951, a value for *b* of 1.65237 - 1.90861, and a value for *MSE* of 0.048428 - 0.073722.

The stem diameter *(d)* is preferably estimated by using a point value for *A* of 3.72932, a point value for *b* of 1.78049, and point value for *MSE* of 0.059088.

The method as defined above is typically used when the trees in respect of which the quantity of sequestered carbon is calculated are of a species of indigenous African savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Rhus pendulina* and the mean approximate tree size of trees of the species *Rhus lancea.*

The estimated stem diameter at ground level *(d)* may be used to obtain an estimated stem circumference at ground level *(c)*.

Typically, the calculation of carbon sequestered by said one of the trees includes the intermediate step of calculating an aboveground dry biomass of said tree, preferably by use of the following equation:

$$\log TDM = 2.397(\log c) - 2.441$$

where:

TDM	=	the estimated aboveground dry biomass of the tree in kilograms; and
c	=	the stem circumference of the tree at ground level, in centimetres.

The method may include the step of calculating the quantity of carbon sequestered by said one of the trees by estimating a fraction of the calculated aboveground dry biomass of the tree which is constituted by sequestered carbon. Calculating the quantity of carbon sequestered by the tree may for instance be by multiplying the aboveground dry biomass (*TDM*) by a factor of 0.6 - 0.9, preferably by a factor of 0.7 - 0.8, and most preferably by a factor of 0.7533.

The abovementioned factor is arrived at by assuming that the total belowground dry biomass is equal to 65-87%, preferably 78% of the aboveground dry biomass (*TDM*). Furthermore, it is assumed that 3-10%, preferably 5.4% of aboveground dry biomass (TDM) is leaf- or foliage dry biomass and should be disregarded. It is estimated that 40-55%, preferably 45% of aboveground dry biomass (*TDM*) is comprised of carbon and in respect of belowground dry biomass, it is estimated that 40-55%, preferably 42% thereof comprises carbon. These estimates translate, when the preferred values are used, to a ratio of 0.7533 of sequestered carbon to aboveground dry biomass.

The method may include calculating the total quantity of carbon sequestered by one of the trees at the end of the predetermined time period, calculating the total quantity of carbon sequestered by that tree at the beginning of the predetermined time period, and subtracting the one calculated value from the other to find the total quantity of carbon sequestered by that tree in the predetermined time period.

Typically, the quantity of sequestered carbon is calculated simultaneously for a plurality of trees of the same species and of the same age, the calculated quantity of carbon sequestered by one of the trees over the predetermined time period being multiplied by the number of trees, to obtain the total quantity of carbon sequestered by the plurality of trees. It should be appreciated that the carbon sequestered by a plurality of trees of varying but similar ages may also be used, the age (*x*) used for this purpose being the mean age of the trees.

The method may include the prior step of planting the trees in respect of which the carbon credits are provided. The method may in such case further include cultivating the trees for the extent of the predetermined time period.

The method will further typically include receiving financial compensation, e.g. payment, in return for providing the carbon credits.

The invention also provides a system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem circumference *(c)* at ground level of the tree at the end of the time period by means of the following equation:

$$c = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

c	=	the estimated value of the stem circumference of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 4.44032 - 4.72672, a value for *b* of 2.17927 - 2.70242, and a value for *MSE* of 0.11467 - 0.19853.

The system is preferably arranged to calculate the stem circumference *(c)* by using a point value for *A* of 4.58352, a point value for *b* of 2.44085, and a point value for *MSE* of 0.14804. The system is typically arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Combretum erythrophyllum*.

The invention yet further provides a system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem circumference *(c)* at ground level of the tree at the end of the time period by means of the following equation:

$$c = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

c	=	the estimated value of the stem circumference of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 4.84110 - 5.01122, a value for *b* of 1.60305 - 1.89217, and a value for *MSE* of 0.044657 - 0.076904.

The system is preferably arranged to calculate the stem circumference *(c)* by using a point value for *A* of 4.92616, a point value for *b* of 1.74761, and a point value for *MSE* of 0.057522. The system is typically arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Rhus lancea*.

The invention extends to a system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem circumference *(c)* at ground level of the tree at the end of the time period by means of the following equation:

$$c = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

c	=	the estimated value of the stem circumference of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 4.32945 - 4.73904, a value for *b* of 1.91382 - 2.51685, and a value for *MSE* of 0.038070 - 0.074931.

The system is preferably arranged to calculate the stem circumference *(c)* by using a point value for *A* of 4.53425, a point value for *b* of 2.21533, and a point value for *MSE* of 0.051892. The system is typically arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Rhus pendulina*.

The invention further extends to a system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem circumference *(c)* at ground level of the tree at the end of the time period by means of the following equation:

$$c = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

c	=	the estimated value of the stem circumference of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 4.68409 - 4.85555, a value for *b* of 1.90258 - 2.20418, and a value for *MSE* of 0.093359 - 0.13699.

The system is preferably arranged to calculate the stem circumference *(c)* by using a point value for *A* of 4.76982, a point value for *b* of 2.05338, and a point value for *MSE* of 0.11204. The system is typically arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of a species of indigenous African savannah tree of which the mean approximate tree size lies between the mean approximate tree size of trees of the species *Combretum erythrophyllum* and the mean approximate tree size of the trees of the species *Rhus lancea*.

The invention also provides a system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem circumference *(c)* at ground level of the tree at the end of the time period by means of the following equation:

$$c = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

c	=	the estimated value of the stem circumference of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 4.79386 - 4.95424, a value for *b* of 1.65237 - 1.90861, and a value for *MSE* of 0.048428 - 0.073722.

The system is preferably arranged to calculate the stem circumference *(c)* by using a point value for *A* of 4.87405, a point value for *b* of 1.78049, and a point value for *MSE* of 0.059088. The system is typically arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of a species of indigenous African savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Rhus pendulina* and the mean approximate tree size of trees of the species *Rhus lancea.*

The invention yet further provides a system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem diameter *(d)* at ground level of the tree at the end of the time period by means of the following equation:

$$d = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

d	=	the estimated value of the stem diameter of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 3.29559 - 3.58199, a value for *b* of 2.17927 - 2.70242, and a value for *MSE* of 0.11467 - 0.19853.

The system is preferably arranged to calculate the stem diameter *(d)* by using a point value for *A* of 3.43879, a point value for *b* of 2.44085, and a point value for *MSE* of 0.14804. The system is typically arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Combretum erythrophyllum*.

The invention also extends to a system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem diameter *(d)* at ground level of the tree at the end of the time period by means of the following equation:

$$d = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

d	=	the estimated value of the stem diameter of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 3.69637 - 3.86649, a value for *b* of 1.60305 - 1.89217, and a value for *MSE* of 0.044657 - 0.076904.

The system is preferably arranged to calculate the stem diameter *(d)* by using a point value for *A* of 3.78143, a point value for *b* of 1.74761, and a point value for *MSE* of 0.057522. The system is typically arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Rhus lancea*.

The invention further provides a system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem diameter *(d)* at ground level of the tree at the end of the time period by means of the following equation:

$$d = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

d	=	the estimated value of the stem diameter of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 3.18472 - 3.59431, a value for *b* of 1.91382 - 2.51685, and a value for *MSE* of 0.038070 - 0.074931.

The system is preferably arranged to calculate the stem diameter *(d)* by using a point value for *A* of 3.38952, a point value for *b* of 2.21533, and a point value for *MSE* of 0.051892. The system is typically arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Rhus pendulina*.

The invention yet further extends to a system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem diameter *(d)* at ground level of the tree at the end of the time period by means of the following equation:

$$d = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

d	=	the estimated value of the stem diameter of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 3.53936 - 3.71082, a value for *b* of 1.90258 - 2.20418, and a value for *MSE* of 0.093359 - 0.13699.

The system is preferably arranged to calculate the stem diameter *(d)* by using a point value for *A* of 3.62509, a point value for *b* of 2.05338, and a point value for *MSE* of 0.11204. The system is typically arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of a species of indigenous African savannah tree of which the mean approximate tree size lies between the mean approximate tree size of trees of the species *Combretum erythrophyllum* and the mean approximate tree size of trees of the species *Rhus lancea*.

The invention also provides a system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem diameter *(d)* at ground level of the tree at the end of the time period by means of the following equation:

$$d = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

d	=	the estimated value of the stem diameter of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 3.64913 - 3.80951, a value for *b* of 1.65237 - 1.90861, and a value for *MSE* of 0.048428 - 0.073722.

The system is preferably arranged to calculate the stem diameter *(d)* by using a point value for *A* of 3.72932, a point value for *b* of 1.78049, and a point value for *MSE* of 0.059088. The system is typically arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of a species of indigenous African savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Rhus pendulina* and the mean approximate tree size of trees of the species *Rhus lancea.*

In instances where the system is arranged to calculate the stem diameter at ground level, the system will preferably be arranged to convert the calculated stem diameter at ground level *(d)* to a corresponding stem circumference at ground level *(c)*.

The system may be arranged to calculate an aboveground dry biomass of the tree as an intermediate step to calculating the quantity of carbon sequestered by the tree, preferably by means of the following equation:

$$\log TDM = 2.397(\log c) - 2.441$$

where:

TDM	=	the estimated aboveground dry biomass of the tree in kilograms; and
c	=	the stem circumference of the tree at ground level, in centimetres.

The system may advantageously be arranged to calculate the quantity of carbon sequestered by the tree by estimating a fraction of the calculated dry biomass of the tree which is constituted by sequestered carbon. The system may thus be arranged to calculate the quantity of carbon sequestered by multiplying the estimated aboveground dry biomass (*TDM*) by a factor of 0.6 - 0.9, preferably by a factor of 0.7 - 0.8, and most preferably be a factor of 0.7533.

The system may further be arranged to calculate the quantity of carbon sequestered by the tree at the end of the predetermined time period, to calculate the total quantity of carbon sequestered by the tree at the beginning of the predetermined time period, and to subtract the one calculated value from the other to find the total quantity of carbon sequestered by the tree in the predetermined time period.

Conveniently, the system may be arranged to calculate the quantity of carbon sequestered by a plurality of trees of the same species and of the same age by multiplying the calculated quantity of carbon sequestered by one of the trees by the number of trees. As explained above, the system may instead be used for a plurality of trees of varying but closely related ages.

Typically, the system comprises an electronic processor and a computer program which contains computer readable instructions for enabling the processor to calculate the quantity of carbon sequestered by a tree or by a plurality of trees, when the program is executed on the processor. The system will thus typically have input means for receiving input from a user, and display means for displaying a calculated quantity of sequestered carbon. The system may preferably be arranged to receive input as to the species of the tree/trees in question, the age of the tree/trees at the start and at the end of the predetermined time period respectively, and the number of trees. The electronic processor, through operation of the computer program, then automatically calculates the quantity of carbon sequestered by the said trees in the time period.

The invention yet further provides carbon credits for offsetting or permitting a particular quantity of carbon emissions, the carbon credits relating to a plurality of trees which sequester carbon over a specific period of time, the particular quantity of emitted carbon permitted or offset by each of the trees being equal to 0.6 - 0.9 times the aboveground dry biomass of the tree, the aboveground dry biomass (*TDM*) of the tree, in kilograms, being such as to satisfy the equation:

$$\log TDM = 2.397(\log c) - 2.441$$

where:

c = the stem circumference of the tree at ground level, in centimetres, and c equals:

$$EXP\left\{\frac{MSE}{2}+\left(A+b.\ln(\ln(x+1))\right)\right\}$$

wherein:

x = the age of said one of the trees at the end of the period, in years,

a set of values for *A, b* and *MSE* being selected from the group of value sets comprising:

A = 4.58352, *b* = 2.44085, *MSE* = 0.14804;
A = 4.92616, *b* = 1.74761, *MSE* = 0.057522;
A = 4.53425, *b* = 2.21533, *MSE* = 0.051892;
A = 4.76982, *b* = 2.05338, *MSE* = 0.11204; and
A = 4.87405, *b* = 1.78049, *MSE* = 0.059088.

It should be appreciated that the values for *A, b* and *MSE* are selected from one of the five listed groups of value sets, and that the combination of values in different value sets does not form part of the invention.

The particular quantity of carbon offset by the carbon credits for each tree may be equal to 0.7 - 0.8 times the aboveground dry biomass (*TDM*) of the tree. Preferably, the particular quantity of carbon offset by the carbon credits for each tree is equal to about 0.75 times the aboveground dry biomass (*TDM*) of the tree, most preferably being equal to 0.7533 times the aboveground dry biomass (*TDM*) of the tree.

The carbon credits will typically relate to a plurality of trees of a species of African Savannah tree. When the carbon credits relate to a plurality of trees of the species *Combretum erythrophyllum,* the values of *A, b* and *MSE* will typically be equal to 4.58352, 2.44085 and 0.14804 respectively.

In cases where the carbon credits relate to a plurality of trees of the species *Rhus lancea*, the values of *A, b* and *MSE* will typically be 4.92616, 1.74761 and 0.057522 respectively. However, when the carbon credits relate to a plurality of trees of the species *Rhus pendulina,* the values of *A, b* and *MSE* will preferably be equal to 4.53425, 2.21533 and 0.051892 respectively.

In cases where the carbon credits relate to a plurality of trees of a species of indigenous South African Savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Combretum erythrophyllum* and the mean approximate tree size of trees of the species *Rhus lancea*, the values of *A, b* and *MSE* may be equal to 4.76982, 2.05338 and 0.11204 respectively. Instead, in cases where the carbon credits relate to a plurality of trees of a species of indigenous South African Savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Rhus lancea* and the mean approximate tree size of trees of the species *Rhus pendulina,* the values of *A, b* and *MSE* may be equal to 4.87405, 1.78049 and 0.059088 respectively.

As explained above, the carbon credits may relate to a quantity of carbon equal to the quantity of carbon sequestered by a representative one of the trees multiplied by the total number of trees.

The invention will now be further described, by way of example.

In this example, a city Municipality plants 500 trees of the African Savannah species *Combretum erythrophyllum*. As an additional source of revenue, the Municipality wishes to sell carbon credits in respect of these trees to an entity, typically a manufacturing company, which emits carbon during manufacture of its products.

It will be appreciated that in terms of international protocols and national guidelines, such companies may be restricted as to the quantity of carbon which may be emitted, and purchase of carbon credits by such a company will serve to offset a particular quantity of carbon emissions, thus increasing the quantity of carbon which the company may emit. It will further be appreciated that, during the growth of a tree, carbon is sequestered from the atmosphere in biochemical processes, thus increasing the dry biomass of the tree, and it is this carbon sequestration which forms the basis for allowing the company to increase its carbon emissions in return for obtaining carbon credits from the Municipality. The total quantity of carbon offset by the carbon credits will thus be equal to the quantity of carbon sequestered by the trees.

The carbon credits are time-based, in that they apply to a predetermined time period. The quantity of carbon emissions offset by the carbon credits is thus equal to the quantity of carbon sequestered by the trees over the predetermined time period. Thus, when the carbon credits apply to, for instance, the first five years of the life of the trees, the total sequestered carbon in the trees at the end of the five years will be offset. However, when the predetermined time period, for instance, applies to years 5 - 10 of the trees' life, the carbon credits will offset the difference between the sequestered carbon at ten years and the sequestered carbon at five years.

In this example, the quantity of carbon offset by the carbon credits relating to the abovementioned 500 *Combretum erythrophyllum* trees is calculated by use of a system for calculating carbon sequestered by the trees. The system comprises an electronic processor provided by a conventional desktop personal computer, and a computer program loaded on the computer. The computer program contains program instructions for enabling the processor of the computer to perform calculation of the quantity of carbon sequestered by the trees, as is explained in more detail below.

When the computer program is executed on the computer, a user is prompted to enter the species of trees in respect of which the sequestered carbon is to be calculated, the number of trees, and the age of the trees at the start and at the end of the time period respectively. In this case, the user will thus enter or select *Combretum erythrophyllum*; 500 trees; an end age of 5 years and a start age of 0 years. The computer then automatically calculates the quantity of carbon sequestered by the trees, and displays the result of this calculation on a display screen.

The computer program is arranged to calculate the quantity of sequestered carbon with reference to the following equation, established by P.J. Peper, E.G. McPherson and S.M. Mori:

$$c = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln\left(\ln\left(x+1\right)\right)\right)\right\} \quad \text{.................................. (1)}$$

where:

c	=	the estimated stem circumference of one of the trees at ground level, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years.

It should be appreciated that the computer program can be arranged to estimate either the stem circumference *(c)* of one of the trees at ground level, or to estimate the stem diameter *(d)* at ground level. In this example, the stem circumference *(c)* is calculated. Furthermore, the values of *A, b,* and *MSE* vary from species to species, and the computer automatically assigns appropriate values to these constants with reference to Table 1 below:

Species	*A*	*b*	*MSE*
Combretum erythrophyllum	4.58352	2.44085	0.14804
Rhus lancea	4.92616	1.74761	0.057522
Rhus pendulina	4.53425	2.21533	0.051892
Combined *C. erythrophyllum* *R. lancea*	4.76982	2.05338	0.11204
Combined *R. lancea* and *R. pendulina*	4.87405	1.78049	0.059088

Table 1

Naturally, these constants will also be different when the computer program is arranged to calculate the stem diameter *(d)* of one of the trees. The respective values of the constants for such a case are set out in Table 2 below.

Use of equation (1) for *Combretum erythrophyllum* at age 5 years, automatically using 4.58352 for *A*, 2.44085 for *b*, and 0.14804 for *MSE*, renders a stem circumference of 437.5 mm, or 43.75 cm. Thereafter, the computer automatically uses the following equation, presented by C.M. Shackleton for South African savannah trees, to calculate the aboveground dry biomass of one of the trees:

$$\log TDM = 2.397(\log c) - 2.441 \qquad (2)$$

where:

TDM = the estimated aboveground dry biomass of the tree in kilograms; and
c = the stem circumference of the tree at ground level, in centimetres.

This results in an estimated aboveground dry biomass (*TDM*) of 31.07 kilograms. It should be borne in mind that carbon is sequestered not only to form aboveground dry biomass (*TDM*), but also to form roots or belowground dry biomass of the tree. The belowground dry biomass (*RDM*), also referred to as root dry matter, of the tree is estimated to be equal to 0.78 x *TDM*, in this case being equal to 24.24 kilograms. It is estimated that 45% of the aboveground dry biomass (*TDM*) consists of carbon, while an estimated 5.4% of aboveground dry biomass (*TDM*) consists of leaves and foliage, which should be disregarded. The aboveground carbon (*AGC*) of one of the trees is thus equal to 0.45(*TDM* - (0.054x*TDM*)) = 13.23 kilograms. The root carbon (*RC*) is estimated to be equal to 42% of the belowground dry biomass (*RDM*), thus being equal to 10.18 kilograms.

The total carbon sequestered by one of the trees is equal to the sum of the root carbon (*RC*) and the aboveground carbon (*AGC*), thus being equal to 23.41 kilograms. It will be appreciated that the total quantity of carbon sequestered by the tree is thus equal to about 0.7533 times the aboveground dry biomass (*TDM*), and that this ratio remains the same for any calculation.

This calculated quantity of carbon sequestered by one of the trees is multiplied by the total number of trees, i.e. 500, to reach a total quantity of sequestered carbon of 11703 kilograms. The Municipality thereafter sells carbon credits to the quantity of 11.70 metric tons of carbon to the manufacturing company, to offset this quantity of emissions by the company.

Carbon emission and sequestrations are sometimes calculated and/or reported in terms of a corresponding quantity of carbon dioxide (CO_2), and to this end, the calculated total quantity of carbon may be multiplied by a factor of 3.67, to obtain the quantity of carbon dioxide which may be emitted in return for purchase of the carbon credits. In this example, the quantity of permitted carbon dioxide emissions will be 42.95 metric tons of CO_2.

It should be appreciated that, although calculation of the quantity of sequestered carbon is performed by the computer in this example, the calculation can be performed manually in other examples. For ease of description, the results of the various equations in the above example are shown to have been rounded off, but it should be appreciated that no rounding off will typically take place when using one result to calculate the next.

In another example of the invention, the Municipality plants 200 trees of the species *Rhus leptodictya*. In this example, the carbon credits relate to a ten year period commencing when the trees are five years of age. As in the example above, a user enters into the computer data in the respective data fields, in particular entering a value of 200 for the number of trees, a value of 5 for the start of the time period, and a value of 15 for the end of the time period.

Since the trees are of a species for which there are no specific values for *A, b,* and *MSE*, respective values for a combination of *Rhus lancea* and *Rhus pendulina* are used. These values are used in this example because the mean approximate tree size of trees of the species *Rhus leptodictya* lies between the mean approximate tree size of trees of the specie *Rhus lancea* and trees of the species *Rhus pendulina*.

The computer automatically assigns the values for *A, b,* and *MSE* according to Table 2 below, the computer in this example being arranged to estimate a stem diameter *(d)* of one of the trees at ground level at the start and at the end of the period.

Species	***A***	***b***	***MSE***
Combretum erythrophyllum	3.43879	2.44085	0.14804
Rhus lancea	3.78143	1.74761	0.057522
Rhus pendulina	3.38952	2.21533	0.051892
Combined *C. erythrophyllum R. lancea*	3.62509	2.05338	0.11204
Combined *R. lancea R pendulina*	3.72932	1.78049	0.059088

Table 2

The following equation is used to calculate the respective stem diameters:

$$d = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\} \quad \text{.....................................(3)}$$

where:

d	=	the estimated value of the diameter of the tree at ground level, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years.

When the values of 3.72932 for *A*, 1.78049 for *b*, and 0.059088 for *MSE*, which are automatically assigned by the computer, are used in equation (3) above, an estimated stem diameter *(d)* of 121.18 mm is obtained. Assuming a circular stem cross-section, the circumference of the tree at five years of age is thus 38.07 centimetres.

Use of equation (2) for this stem circumference, results in an estimated aboveground dry biomass (*TDM*) of 22.27 kilograms. Multiplication of the calculated aboveground dry biomass (*TDM*) with a factor of 0.7533, as explained above, provides a total quantity of carbon sequestered by one of the trees at age five of 16.77 kilograms.

Similar calculation of the total carbon sequestered by one of the trees at age fifteen provides 108.09 kilograms. The difference between these two values indicates the total quantity of carbon sequestered by one of the trees during the ten year period to which the carbon credits apply, thus equaling 91.32 kilograms. In total, the 200 trees thus sequestered 18.26 metric tons of carbon, and the carbon credits sold in respect of these trees offsets an equal quantity of carbon emissions.

CLAIMS

1. A method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem circumference *(c)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$c_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

c_i	=	the estimated value of the stem circumference of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

and by using a value for *A* of 4.44032 - 4.72672, a value for *b* of 2.17927 - 2.70242, and a value for *MSE* of 0.11467 - 0.19853.

2. A method as claimed in claim 1, in which the stem circumference *(c)* is estimated by using a point value for *A* of 4.58352, a point value for *b* of 2.44085, and a point value for *MSE* of 0.14804.

3. A method as claimed in claim 1 or claim 2, in which the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Combretum erythrophyllum*.

4. A method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem circumference *(c)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$c_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

c_i	=	the estimated value of the stem circumference of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

and by using a value for *A* of 4.84110 - 5.01122, a value for *b* of 1.60305 - 1.89217, and a value for *MSE* of 0.044657 - 0.076904.

5. A method as claimed in claim 4, in which the stem circumference *(c)* is estimated by using a point value for *A* of 4.92616, a point value for *b* of 1.74761, and a point value for *MSE* of 0.057522.

6. A method as claimed in claim 4 or claim 5, in which the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Rhus lancea*.

7. A method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem circumference *(c)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$c_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

c_i	=	the estimated value of the stem circumference of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

using a value for *A* of 4.32945 - 4.73904, a value for *b* of 1.91382 - 2.51685, and a value for *MSE* of 0.038070 - 0.074931.

8. A method as claimed in claim 7, in which the stem circumference *(c)* is estimated by using a point value for *A* of 4.53425, a point value for *b* of 2.21533, and a point value for *MSE* of 0.051892.

9. A method as claimed in claim 7 or claim 8, in which the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Rhus pendulina*.

10. A method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem circumference *(c)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$c_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

c_i	=	the estimated value of the stem circumference of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

using a value for *A* of 4.68409 - 4.85555, a value for *b* of 1.90258 - 2.20418, and a value for *MSE* of 0.093359 - 0.13699.

11. A method as claimed in claim 10, in which the stem circumference *(c)* is estimated by using a point value for *A* of 4.76982, a point value for *b* of 2.05338, and a point value for *MSE* of 0.11204.

12. A method as claimed in claim 10 or claim 11, in which the trees in respect of which the quantity of sequestered carbon is calculated are of a species of indigenous African savannah tree of which the mean approximate tree size lies between the mean approximate tree size of trees of the species *Combretum erythrophyllum* and the mean approximate tree size of trees of the species *Rhus lancea.*

13. A method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem circumference *(c)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$c_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln\left(\ln\left(x_i + 1\right)\right)\right)\right\}$$

where:

c_i	=	the estimated value of the stem circumference of the i[th] tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i[th] tree, in years,

using a value for *A* of 4.79386 - 4.95424, a value for *b* of 1.65237 - 1.90861, and a value for *MSE* of 0.048428 - 0.073722.

14. A method as claimed in claim 13, in which the stem circumference *(c)* is estimated by using a point value for *A* of 4.87405, a point value for *b* of 1.78049, and a point value for *MSE* of 0.059088.

15. A method as claimed in claim 13 or claim 14, in which the trees in respect of which the quantity of sequestered carbon is calculated are of a species of indigenous African savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Rhus pendulina* and the mean approximate tree size of trees of the species *Rhus lancea.*

16. A method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem diameter *(d)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$d_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln\left(\ln\left(x_i + 1\right)\right)\right)\right\}$$

where:

d_i	=	the estimated value of the stem diameter of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

and by using a value for *A* of 3.29559 - 3.58199, a value for *b* of 2.17927 - 2.70242, and a value for *MSE* of 0.11467 - 0.19853.

17. A method as claimed in claim 16, in which the stem diameter *(d)* is estimated by using a point value for *A* of 3.43879, a point value for *b* of 2.44085, and a point value for *MSE* of 0.14804.

18. A method as claimed in claim 16 or claim 17, in which the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Combretum erythrophyllum*.

19. A method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem diameter *(d)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$d_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

d_i	=	the estimated value of the stem diameter of the i^{th} tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i^{th} tree, in years,

using a value for *A* of 3.69637 - 3.86649, a value for *b* of 1.60305 - 1.89217, and a value for *MSE* of 0.044657 - 0.076904.

20. A method as claimed in claim 19, in which the stem diameter *(d)* is estimated by using a point value for *A* of 3.78143, a point value for *b* of 1.74761, and a point value for *MSE* of 0.057522.

21. A method as claimed in claim 19 or claim 20, in which the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Rhus lancea*.

22. A method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem diameter *(d)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$d_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln\left(\ln\left(x_i + 1\right)\right)\right)\right\}$$

where:

d_i	=	the estimated value of the stem diameter of the i[th] tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i[th] tree, in years,

and by using a value for *A* of 3.18472 - 3.59431, a value for *b* of 1.91382 - 2.51685, and a value for *MSE* of 0.038070 - 0.074931.

23. A method as claimed in claim 22, in which the stem diameter *(d)* is estimated by using a point value for *A* of 3.38952, a point value for *b* of 2.21533, and a point value for *MSE* of 0.051892.

24. A method as claimed in claim 22 or claim 23, in which the trees in respect of which the quantity of sequestered carbon is calculated are of the species *Rhus pendulina*.

25. A method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem diameter *(d)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$d_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln\left(\ln\left(x_i + 1\right)\right)\right)\right\}$$

where:

d_i	=	the estimated value of the stem diameter of the i[th] tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the i[th] tree, in years,

and by using a value for *A* of 3.53936 - 3.71082, a value for *b* of 1.90258 - 2.20418, and a value for *MSE* of 0.093359 - 0.13699.

26. A method as claimed in claim 25, in which the stem diameter *(d)* is estimated by using a point value for *A* of 3.62509, a point value for *b* of 2.05338, and a point value for *MSE* of 0.11204.

27. A method as claimed in claim 25 or claim 26, in which the trees in respect of which the quantity of sequestered carbon is calculated are of a species of indigenous African savannah tree of which the mean approximate tree size lies between the mean approximate tree size of trees of the species *Combretum erythrophyllum* and the mean approximate tree size of trees of the species *Rhus lancea.*

28. A method of ameliorating the ecological effects of carbon emissions, which method includes providing carbon credits to an entity to offset a quantity of emitted carbon, the quantity of emitted carbon offset by the carbon credits being equal to a calculated quantity of carbon

sequestered by an associated plurality of trees over a predetermined time period, the method including the step of calculating the quantity of carbon sequestered by each of the trees over the predetermined period by estimating the value of the stem diameter *(d)* of one of the trees at ground level at the end of the predetermined time period by use of the following equation:

$$d_i = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x_i + 1))\right)\right\}$$

where:

d_i	=	the estimated value of the stem diameter of the ith tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x_i	=	the value of the age of the ith tree, in years,

and by using a value for *A* of 3.64913 - 3.80951, a value for *b* of 1.65237 - 1.90861, and a value for *MSE* of 0.048428 - 0.073722.

29. A method as claimed in claim 28, in which the stem diameter *(d)* is estimated by using a point value for *A* of 3.72932, a point value for *b* of 1.78049, and a point value for *MSE* of 0.059088.

30. A method as claimed in claim 28 or claim 29, in which the trees in respect of which the quantity of sequestered carbon is calculated are of a species of indigenous African savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Rhus pendulina* and the mean approximate tree size of trees of the species *Rhus lancea.*

31. A method as claimed in any one of claims 16 to 30 inclusive, in which the estimated stem diameter at ground level *(d)* is used to obtain an estimated stem circumference at ground level *(c)*.

32. A method as claimed in any one of claims 1 to 31 inclusive, in which the calculation of carbon sequestered by said one of the trees includes the intermediate step of calculating an aboveground dry biomass of said tree.

33. A method as claimed in claim 32, in which calculating the aboveground dry biomass of said one of the trees is by means of the following equation:

$$\log TDM = 2.397(\log c) - 2.441$$

where:

TDM	=	the estimated aboveground dry biomass of the tree in kilograms; and
c	=	the stem circumference of the tree at ground level, in centimetres.

34. A method as claimed in claim 32 or claim 33, which includes the step of calculating the quantity of carbon sequestered by said one of the trees by estimating a fraction of the calculated aboveground dry biomass of the tree which is constituted by sequestered carbon.

35. A method as claimed in claim 34, in which calculating the quantity of carbon sequestered is by multiplying the aboveground dry biomass (*TDM*) by a factor of 0.6 - 0.9.

36. A method as claimed in claim 34, in which calculating the carbon sequestered by said tree is by multiplying the aboveground dry biomass (*TDM*) by a factor of 0.7533.

37. A method as claimed in any one of the preceding claims, which includes calculating the total quantity of carbon sequestered by one of the trees at the end of the predetermined time period, calculating the total quantity of carbon sequestered by that tree at the beginning of the predetermined time period, and subtracting the one calculated value from the other to find the total quantity of carbon sequestered by that tree in the predetermined time period.

38. A method as claimed in any one of the preceding claims, in which the quantity of sequestered carbon is calculated simultaneously for a plurality of trees of the same species and of the same age, the calculated quantity of carbon sequestered by one of the trees over the predetermined time period being multiplied by the number of trees, to obtain the total quantity of carbon sequestered by the plurality of trees.

39. A method as claimed in any one of the preceding claims, which includes receiving financial compensation in return for the provision of the carbon credits.

40. A system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem circumference *(c)* at ground level of the tree at the end of the time period by means of the following equation:

$$c = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

c	=	the estimated value of the stem circumference of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 4.44032 - 4.72672, a value for *b* of 2.17927 - 2.70242, and a value for *MSE* of 0.11467 - 0.19853.

41. A system as claimed in claim 40, which is arranged to calculate the stem circumference *(c)* by using a point value for *A* of 4.58352, a point value for *b* of 2.44085, and a point value for *MSE* of 0.14804.

42. A system as claimed in claim 40 or claim 41, which is arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Combretum erythrophyllum*.

43. A system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem circumference *(c)* at ground level of the tree at the end of the time period by means of the following equation:

$$c = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

c	=	the estimated value of the stem circumference of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 4.84110 - 5.01122, a value for *b* of 1.60305 - 1.89217, and a value for *MSE* of 0.044657 - 0.076904.

44. A system as claimed in claim 43, which is arranged to calculate the stem circumference *(c)* by using a point value for *A* of 4.92616, a point value for *b* of 1.74761, and a point value for *MSE* of 0.057522.

45. A system as claimed in claim 43 or claim 44, which is arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Rhus lancea*.

46. A system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem circumference *(c)* at ground level of the tree at the end of the time period by means of the following equation:

$$c = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln\left(\ln\left(x+1\right)\right)\right)\right\}$$

where:

c	=	the estimated value of the stem circumference of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 4.32945 - 4.73904, a value for *b* of 1.91382 - 2.51685, and a value for *MSE* of 0.038070 - 0.074931.

47. A system as claimed in claim 46, which is arranged to calculate the stem circumference *(c)* by using a point value for *A* of 4.53425, a point value for *b* of 2.21533, and a point value for *MSE* of 0.051892.

48. A system as claimed in claim 46 or claim 47, which is arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Rhus pendulina*.

49. A system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem circumference *(c)* at ground level of the tree at the end of the time period by means of the following equation:

$$c = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln\left(\ln\left(x+1\right)\right)\right)\right\}$$

where:

c	=	the estimated value of the stem circumference of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 4.68409 - 4.85555, a value for *b* of 1.90258 - 2.20418, and a value for *MSE* of 0.093359 - 0.13699.

50. A system as claimed in claim 49, which is arranged to calculate the stem

circumference *(c)* by using a point value for *A* of 4.76982, a point value for *b* of 2.05338, and a point value for *MSE* of 0.11204.

51. A system as claimed in claim 49 or claim 50, which is arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of a species of indigenous African savannah tree of which the mean approximate tree size lies between the mean approximate tree size of trees of the species *Combretum erythrophyllum* and the mean approximate tree size of the trees of the species *Rhus lancea*.

52. A system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem circumference *(c)* at ground level of the tree at the end of the time period by means of the following equation:

$$c = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

c	=	the estimated value of the stem circumference of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 4.79386 - 4.95424, a value for *b* of 1.65237 - 1.90861, and a value for *MSE* of 0.048428 - 0.073722.

53. A system as claimed in claim 52, which is arranged to calculate the stem circumference *(c)* by using a point value for *A* of 4.87405, a point value for *b* of 1.78049, and a point value for *MSE* of 0.059088.

54. A system as claimed in claim 52 or claim 53, which is arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of a species of indigenous African savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Rhus pendulina* and the mean approximate tree size of trees of the species *Rhus lancea.*

55. A system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem diameter *(d)* at ground level of the tree at the end of the time period by means of the following equation:

$$d = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

d	=	the estimated value of the stem diameter of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 3.29559 - 3.58199, a value for *b* of 2.17927 - 2.70242, and a value for *MSE* of 0.11467 - 0.19853.

56. A system as claimed in claim 55, which is arranged to calculate the stem diameter

(d) by using a point value for *A* of 3.43879, a point value for *b* of 2.44085, and a point value for *MSE* of 0.14804.

57. A system as claimed in claim 55 or claim 56, which is arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Combretum erythrophyllum*.

58. A system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem diameter *(d)* at ground level of the tree at the end of the time period by means of the following equation:

$$d = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln\left(\ln\left(x+1\right)\right)\right)\right\}$$

where:

d	=	the estimated value of the stem diameter of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 3.69637 - 3.86649, a value for *b* of 1.60305 - 1.89217, and a value for *MSE* of 0.044657 - 0.076904.

59. A system as claimed in claim 58, which is arranged to calculate the stem diameter *(d)* by using a point value for *A* of 3.78143, a point value for *b* of 1.74761, and a point value for *MSE* of 0.057522.

60. A system as claimed in claim 58 or claim 59, which is arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Rhus lancea*.

61. A system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem diameter *(d)* at ground level of the tree at the end of the time period by means of the following equation:

$$d = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln\left(\ln\left(x+1\right)\right)\right)\right\}$$

where:

d	=	the estimated value of the stem diameter of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 3.18472 - 3.59431, a value for *b* of 1.91382 - 2.51685, and a value for *MSE* of 0.038070 - 0.074931.

62. A system as claimed in claim 61, which is arranged to calculate the stem diameter *(d)* by using a point value for *A* of 3.38952, a point value for *b* of 2.21533, and a point value for *MSE* of 0.051892.

63. A system as claimed in claim 61 or claim 62, which is arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of the species *Rhus pendulina*.

64. A system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem diameter *(d)* at ground level of the tree at the end of the time period by means of the following equation:

$$d = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

d	=	the estimated value of the stem diameter of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 3.53936 - 3.71082, a value for *b* of 1.90258 - 2.20418, and a value for *MSE* of 0.093359 - 0.13699.

65. A system as claimed in claim 64, which is arranged to calculate the stem diameter *(d)* by using a point value for *A* of 3.62509, a point value for *b* of 2.05338, and a point value for *MSE* of 0.11204.

66. A system as claimed in claim 64 or claim 65, which is arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon is calculated is of a species of indigenous African savannah tree of which the mean approximate tree size lies between the mean approximate tree size of trees of the species *Combretum erythrophyllum* and the mean approximate tree size of trees of the species *Rhus lancea*.

67. A system for calculating the quantity of carbon sequestered by a tree over a predetermined time period, the system being arranged to estimate the stem diameter *(d)* at ground level of the tree at the end of the time period by means of the following equation:

$$d = EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

d	=	the estimated value of the stem diameter of the tree, in millimeters;
EXP	=	the inverse of the natural logarithm;
A, b, MSE	=	pre-estimated constants which have different values for different species of tree; and
x	=	the value of the age of the tree, in years,

and by using a value for *A* of 3.64913 - 3.80951, a value for *b* of 1.65237 - 1.90861, and a value for *MSE* of 0.048428 - 0.073722.

68. A system as claimed in claim 67, which is arranged to calculate the stem diameter *(d)* by using a point value for *A* of 3.72932, a point value for *b* of 1.78049, and a point value for *MSE* of 0.059088.

69. A system as claimed in claim 67 or claim 68, which is arranged automatically to use said values for *A, b,* and *MSE* when the tree in respect of which the quantity of sequestered carbon

is calculated is of a species of indigenous African savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Rhus pendulina* and the mean approximate tree size of trees of the species *Rhus lancea.*

70. A system as claimed in any one of claims 55 to 69 inclusive, which is arranged to convert the calculated stem diameter at ground level *(d)* to a corresponding stem circumference at ground level *(c)*.

71. A system as claimed in any one of claims 40 to 70 inclusive, which is arranged to calculate an aboveground dry biomass of the tree as an intermediate step to calculating the quantity of carbon sequestered by the tree.

72. A system as claimed in claim 71, which is arranged to calculate the aboveground dry biomass of each tree by means of the following equation:

$$\log TDM = 2.397(\log c) - 2.441$$

where:

TDM	=	the estimated aboveground dry biomass of the tree in kilograms; and
c	=	the stem circumference of the tree at ground level, in centimetres.

73. A system as claimed in claim 71 or claim 72, which is arranged to calculate the quantity of carbon sequestered by the tree by estimating a fraction of the calculated dry biomass of the tree which is constituted by sequestered carbon.

74. A system as claimed in claim 73, which is arranged to calculate the quantity of carbon sequestered by multiplying the estimated aboveground dry biomass (*TDM*) by a factor of 0.6 - 0.9.

75. A system as claimed in claim 73, which is arranged to calculate the carbon sequestered by each tree by multiplying the estimated aboveground dry biomass (*TDM*) by a factor of 0.7533.

76. A system as claimed in any one of claims 40 to 75 inclusive, which is arranged to calculate the quantity of carbon sequestered by the tree at the end of the predetermined time period, to calculate the total quantity of carbon sequestered by the tree at the beginning of the predetermined time period, and to subtract the one calculated value from the other to find the total quantity of carbon sequestered by the tree in the predetermined time period.

77. A system as claimed in any one of claims 40 to 76, which is arranged to calculate the quantity of carbon sequestered by a plurality of trees of the same species and of the same age by multiplying the calculated quantity of carbon sequestered by one of the trees by the number of trees.

78. A system as claimed in any one of claims 40 to 77, which comprises an electronic processor and a computer program having computer readable instructions for enabling the processor to calculate the quantity of carbon sequestered by a tree or by a plurality of trees, when the program is executed on the processor.

79. Carbon credits for offsetting or permitting a particular quantity of carbon emissions, the carbon credits relating to a plurality of trees which sequester carbon over a specific period of time, the particular quantity of emitted carbon permitted or offset by each of the trees being equal to about 0.6 - 0.9 times the aboveground dry biomass of the tree, the aboveground dry biomass (*TDM*) of the tree, in kilograms, being such as to satisfy the equation:

$$\log TDM = 2.397(\log c) - 2.441$$

where:

c = the stem circumference of the tree at ground level, in centimetres, and c equals, in millimetres:

$$EXP\left\{\frac{MSE}{2} + \left(A + b.\ln(\ln(x+1))\right)\right\}$$

where:

x = the age of the tree at the end of the period, in years,

a set of values for *A, b* and *MSE* being selected from the group of value sets comprising:

A = 4.58352, *b* = 2.44085, *MSE* = 0.14804;
A = 4.92616, *b* = 1.74761, *MSE* = 0.057522;
A = 4.53425, *b* = 2.21533, *MSE* = 0.051892;
A = 4.76982, *b* = 2.05338, *MSE* = 0.11204; and
A = 4.87405, *b* = 1.78049, *MSE* = 0.059088.

80. Carbon credits as claimed in claim 79, in which the particular quantity of carbon offset by each tree is equal to 0.7 - 0.8 times the aboveground dry biomass (*TDM*) of the tree.

81. Carbon credits as claimed in claim 79, in which the particular quantity of carbon offset by each tree is equal to about 0.75 times the aboveground dry biomass (*TDM*) of the tree.

82. Carbon credits as claimed in claim 79, in which the particular quantity of carbon offset by each tree is equal to about 0.7533 times the aboveground dry biomass (*TDM*) of the tree.

83. Carbon credits as claimed in any one of claims 79 to 82 inclusive, in which the carbon credits relate to a plurality of trees of a species of African Savannah tree.

84. Carbon credits as claimed in claim 83, in which the carbon credits relate to a plurality of trees of the species *Combretum erythrophyllum*, the values of *A, b* and *MSE* being equal to 4.58352, 2.44085 and 0.14804 respectively.

85. Carbon credits as claimed in claim 83, in which the carbon credits relate to a plurality of trees of the species *Rhus lancea,* the values of *A, b* and *MSE* being equal to 4.92616, 1.74761 and 0.057522 respectively.

86. Carbon credits as claimed in claim 83, in which the carbon credits relate to a plurality of trees of the species *Rhus pendulina,* the values of *A, b* and *MSE* being equal to 4.53425, 2.21533 and 0.051892 respectively.

87. Carbon credits as claimed in claim 83, in which the carbon credits relate to a plurality of trees of a species of indigenous South African Savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Combretum erythrophyllum* and the mean approximate tree size of trees of the species *Rhus lancea,* the values of *A, b* and *MSE* being equal to 4.76982, 2.05338 and 0.11204 respectively.

88. Carbon credits as claimed in claim 83, in which the carbon credits relate to a plurality of trees of a species of indigenous South African Savannah tree of which the mean approximate tree size is between the mean approximate tree size of trees of the species *Rhus lancea* and the mean approximate tree size of trees of the species *Rhus pendulina,* the values of *A, b* and *MSE* being equal to 4.87405, 1.78049 and 0.059088 respectively.

89. A method as claimed in any one of claims 1, 4, 7, 10, 13, 16, 19, 22, 25 and 28 inclusive, substantially as herein described and illustrated.

90. A system as claimed in any one of claims 40, 43, 46, 49, 52, 55, 58, 61, 64 and 67 inclusive, substantially as herein described and illustrated.

91. Carbon credits as claimed in claim 79, substantially as herein described and illustrated.