Supplementary material:
The role of vegetation in the CO_2 flux from a tropical urban neighbourhood

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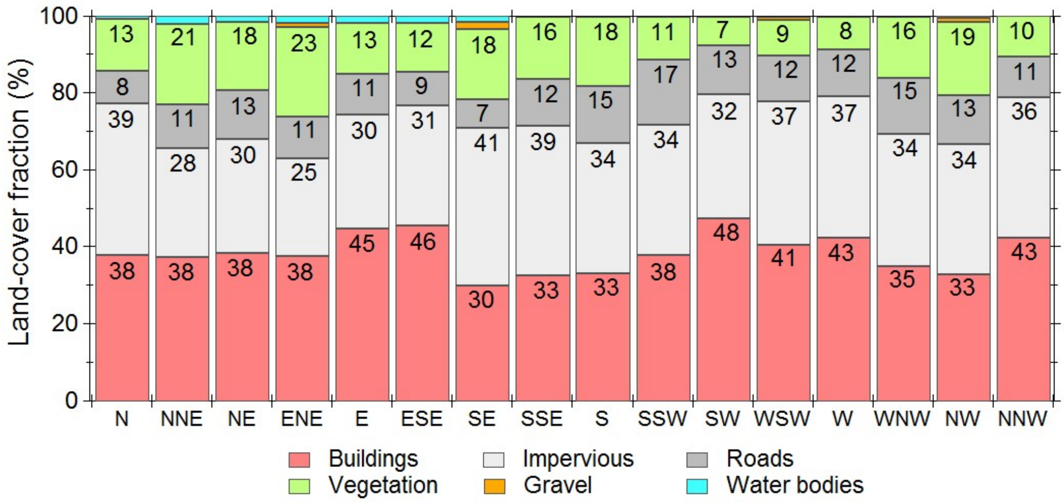

Figure S1. Land cover within a 1000-m radius centered on the EC tower. Impervious surfaces include parking lots and other surface covered by concrete or asphalt.

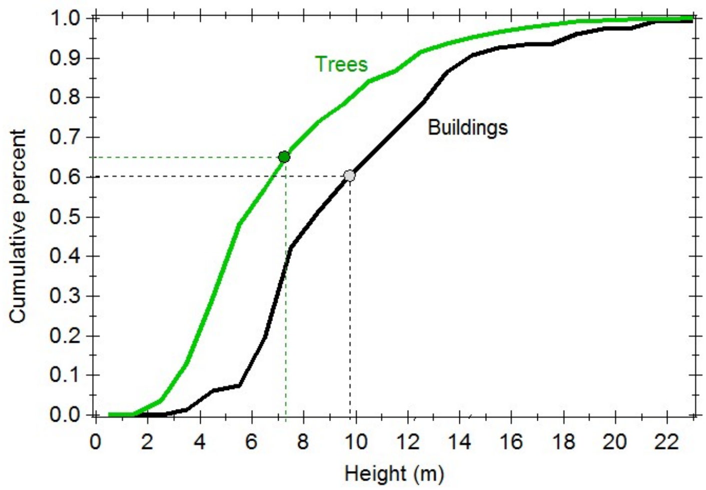

Figure S2. Cumulative probability density distribution of height of trees and buildings within a radius of 500 and 350 m, respectively centered on the EC tower. Markers and dotted lines indicate average height of trees and buildings. 80% of the trees and buildings have heights below 9.8 and 12.8 m, respectively. Heights were measured using a laser rangefinder (TruPulse 200; Laser Tech Inc.) with an accuracy of ±30 cm for targets at a distance of 75 m.

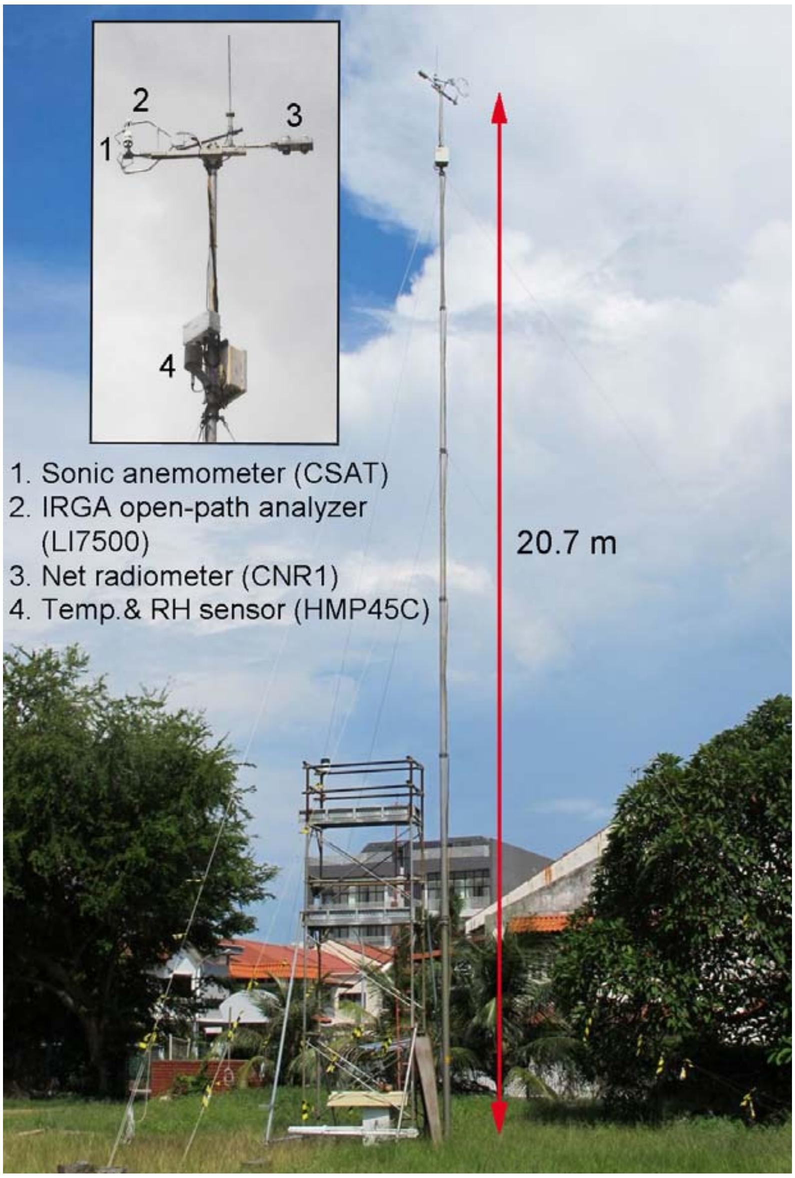

Figure S3. Photograph of the flux tower and EC system (inset). The azimuth orientation of the sonic anemometer corresponds to the main wind direction of the prevailing monsoon season (180° or 30°).

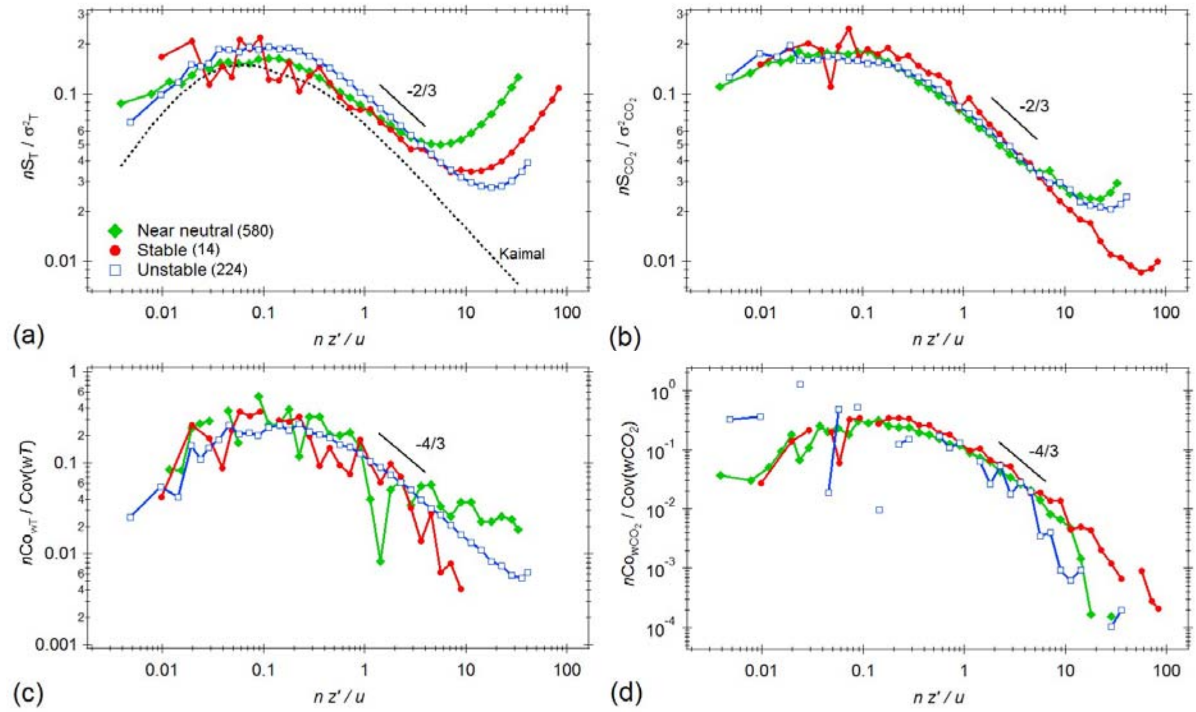

Figure S4. Composite (co)spectra of (a) virtual temperature (b) CO_2, and fluxes of (c) sensible heat and (d) CO_2, for three stability ranges (unstable: $z'/L < -0.1$, near neutral: $-0.1 \leq z'/L < 0.1$, and stable: $z'/L \geq 0.1$. L is Obukhov length and z' is effective measurement height ($z' = z_m - z_d$)). Results are based on 818 30-min periods with at least 17,700 10 Hz data points each, measured between 2-22 February 2012. Numbers in parenthesis in (a) are number of periods for each stability category. The (co)spectral energy densities are normalized by their respective (co)variance and plotted as a function of a non-dimensional frequency where n is natural frequency and u is mean horizontal wind speed. The dashed line in (a) represents a neutral reference spectra for a flat, ideal surface (Kaimal et al. 1972).

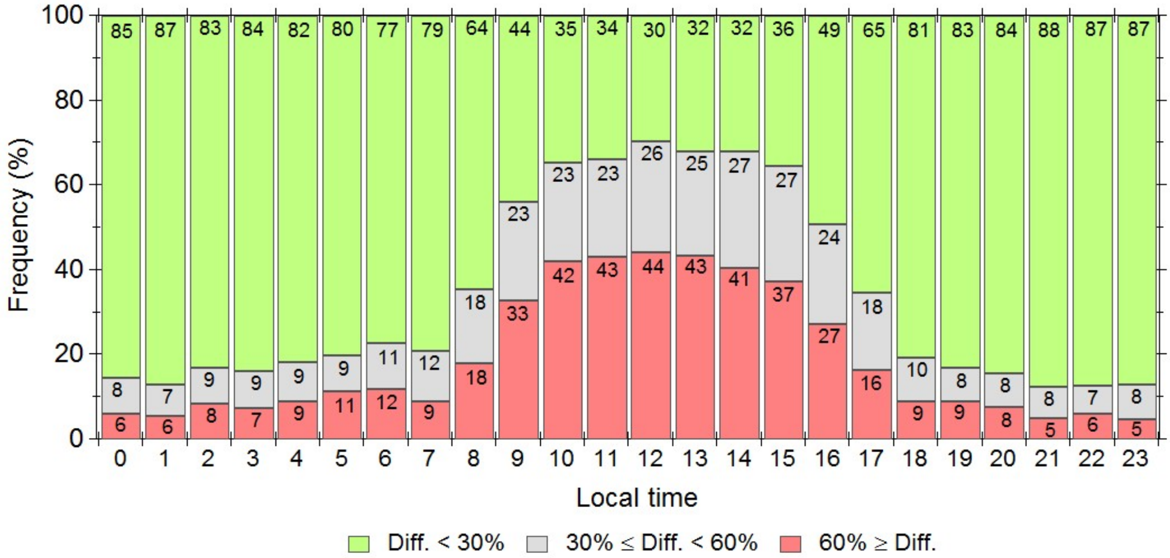

Figure S5. Frequency distribution of (non)stationary conditions according to time of day during the entire measurement period. Numbers inside bars indicate percentage of periods for each of the following three stationarity conditions determined using criterion proposed by Aubinet et al. (2000). If the difference between the flux obtained from a 30-min average and the average of fluxes from six continuous 5-min subperiods during the same 30-min period is less than 30% data meet and exceed the stationarity criteria. If the difference is between 30% and 60% data are of acceptable quality. When the difference is larger than 60% data do not fulfil the stationarity requirements and are discarded from further analysis.

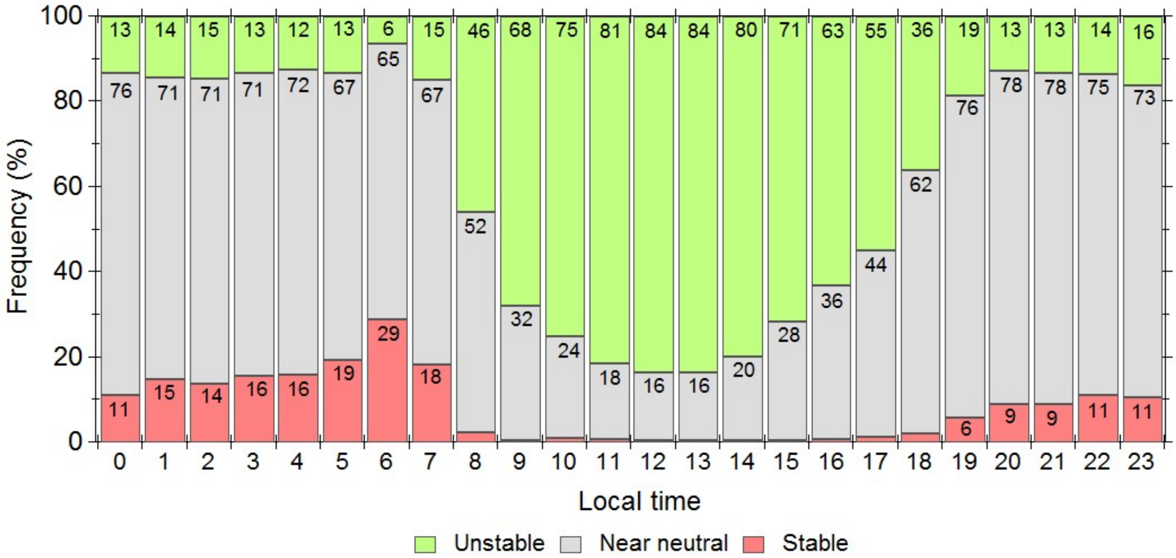

Figure S6. Frequency distribution of atmospheric stability during the entire measurement period. Numbers inside bars indicate percentage of periods for each stability condition defined in Fig. S4.

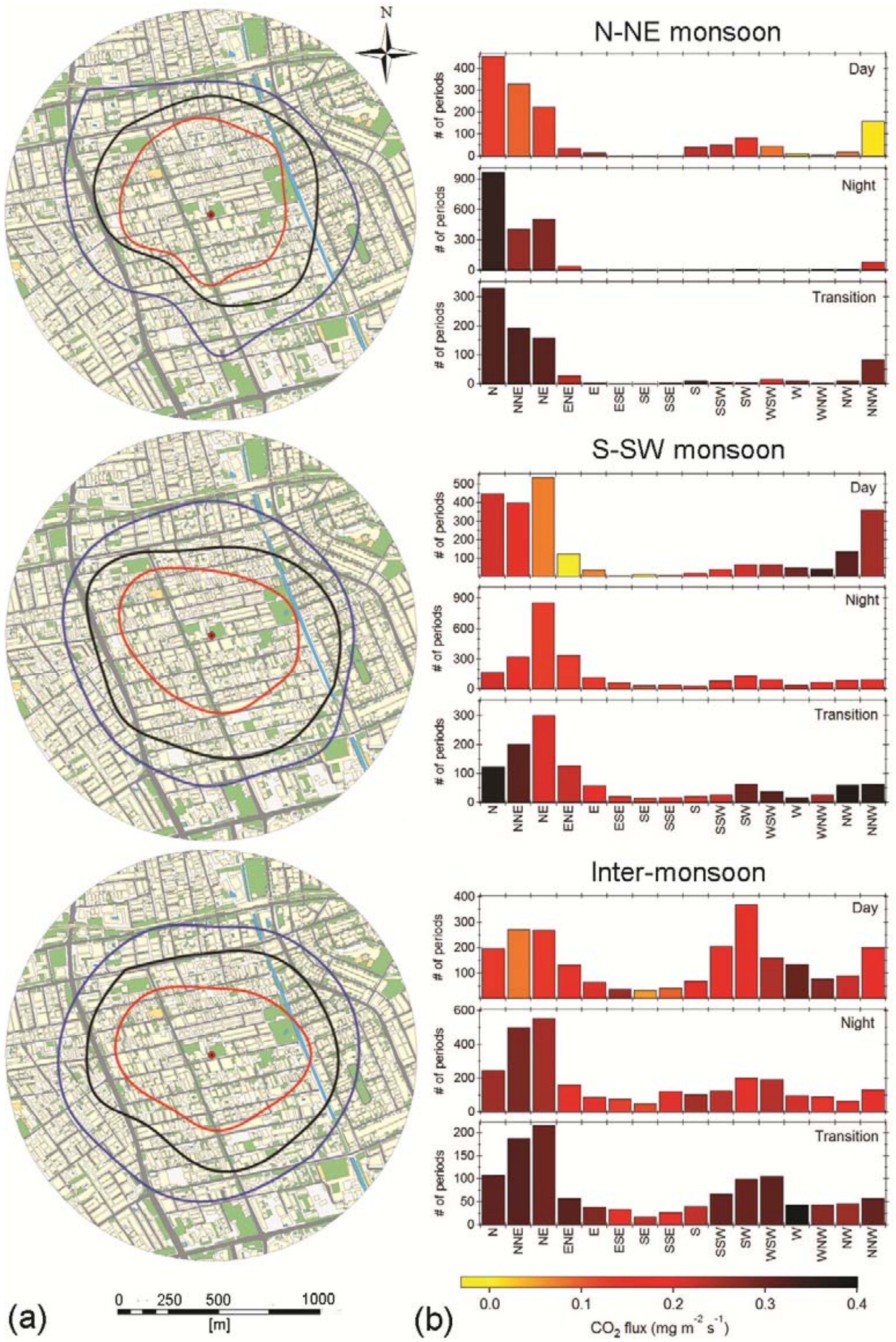

Figure S7. (a) Footprints encompassing 80% of the EC flux source area overlaid on a land cover map centred on the EC tower location (red dot) and (b) number of EC 30-min periods (after data post-processing and quality control) as a function of wind direction for three different periods of the day: Day (8 – 18 h), Night (20 – 6 h) and Transition (two hours centred on sunrise and sunset, respectively). Red, blue and black contours in (a) are the average footprints for each wind direction during Day, Night and the entire day, respectively. Colour of bars in (b) indicates average CO_2 flux observed for each wind direction sector. N-NE monsoon corresponds to year days 335-74, S-SW monsoon to 121-273 and Inter-monsoon to 75-120 and 274-334.

Emissions from vehicular traffic

This section describes the procedures and input data used to estimate the CO_2 emissions from on-road mobile sources. The emissions were calculated using the Mobile Vehicles Emissions Simulator 2010 (MOVES2010) developed by the United States Environmental Protection Agency (US-EPA). MOVES2010 uses a discrete binning approach to estimate vehicle emissions. Each activity (e.g. vehicle distance travelled) is categorized into different bins according to the operating mode and source characteristics. An emission factor is then assigned to each unique combination of operating mode and source bin and further aggregated by vehicle type (US-EPA, 2010). This approach to calculate emission factors allows for the driving mode of vehicles (including acceleration or deceleration) to be taken into account and results in a better representation of real driving conditions (Vallamsundar and Lin, 2010). The Project Domain/Scale mode was selected for the present study. This mode allows emissions modeling from a specific road network with site-specific inputs (USEPA, 2010), such as traffic volume per road, fleet composition and age, road lengths, traveling speeds and local meteorology.

The hourly diurnal traffic volume per road was obtained from automatic counters and manual counts. The Land Transport Authority (LTA) of Singapore provided continuous traffic counts for 13 different automatic counters located at main intersections in the study area (Fig. S8) from June 2010 to June 2011. Additional manual counts were conducted at 9 minor roads within the study area to estimate the fraction of traffic flow that minor roads experience as compared to major roads. This fraction was then used to estimate the 24-hour continuous total traffic volume for the entire network of roads.

Figure S8. Map of study area showing locations of 12 road intersections equipped with automatic traffic counters (red stars). Traffic intersection numbers correspond to LTA database. Intersection 6112 lies to the Southeast, just outside the 1000 m radius of the study area.

The manual observations were also used to determine fleet composition. The number of vehicles by type was counted for 20 minutes every hour from 6 to 21 h during four days. Five different types of vehicle in MOVES2010 corresponding to the types of vehicles found in Singapore were selected: motorcycles, passenger cars (private cars and taxis), light commercial trucks (lorries and vans), transit buses (minibuses and public buses), and single unit short-haul trucks (container and refuse trucks). Taxis were initially considered as a separate category since they predominantly run on diesel-fuel in Singapore. They were later combined with the passenger car category, comprising the major fraction of diesel-fuel vehicles in this category.

The results from the surveyed roads (e.g. fleet composition) were applied to streets where no manual counts were conducted. Similarly, for the fleet composition during nighttime hours (21 – 6 h) when no manual surveying was conducted, the average of the first and last set of manual counts of the day was used. Public buses do not operate from midnight to 6 h and were excluded from this period. The age distribution for each of the five vehicle types in Singapore was obtained from the Land Transport Authority website (LTA, 2011).

Figure S9 shows the diurnal traffic flow for different domain sizes and by vehicle composition. As expected, passenger cars make up the bulk of the traffic throughout the day (71.3%). This is followed by light commercial vehicles (18.4%), motorcycles (5.6%), transit buses (3.2%), and single unit short-haul truck (1.5%).

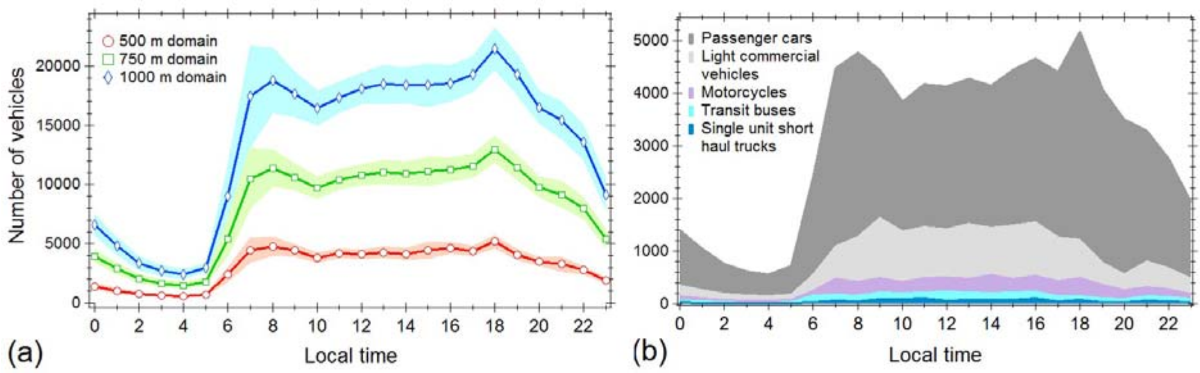

Figure S9. (a) Diurnal variability of traffic volume on weekdays within 500, 750 and 1000 m circle domains centered on the EC tower. Shaded areas represent ±1 standard deviations. (b) Diurnal variability of traffic volume by vehicle type within the 500 m circle domain.

Traffic emissions were calculated for three domains (500, 750 and 1000 m circle radius centered on the EC tower location) using three average vehicle speeds (45, 50 and 55 km h^{-1}) across the entire domain. The length of each road was measured from the land-use cover map shown in Fig. 1 in the main text. Ambient temperature and relative humidity were taken from the EC system data. As mentioned in the main text the traffic emissions were only calculated for weekdays. Figure S10 presents diurnal emissions for two domains and two traveling speeds.

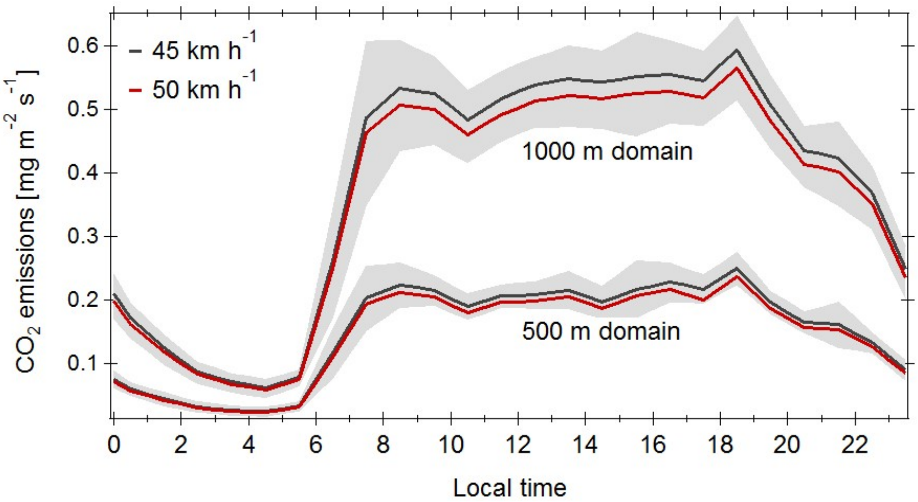

Figure S10. Diurnal variability of weekday traffic emissions for 500 and 1000 m circle domains and traveling speeds of 45 and 50 km h^{-1}. Grey shaded areas represent ±1 standard deviation for emissions at 45 km h^{-1} calculated from the traffic variability within each domain.

Emissions from human breathing

This section describes the sources and characteristics of the data used to estimate the CO_2 emissions from human breathing. The population distribution by age and gender was obtained from the population census (Singapore Department of Statistics, 2011). The weight distribution by gender and age was calculated from the daily intake and recommended daily allowances of energy for adult Singaporeans (Health Promotion Board, 2004). The weight distribution for children was obtained from anthropometric charts (National Healthcare Group Polyclinics, 2000; School Health Service, 1993). A per capita metabolic emission of 621 and 677 g day^{-1} was determined for adult women and men, respectively. The diurnal variation of population was based on the resident labour force participation rate by gender and age (Ministry of Manpower, 2011). Although the official working day in Singapore is eight hours, we assumed that working residents spend 12 hours outside their houses. School hours varied according to school grade from five hours in kindergarten to 8.5 hours in high school. Table S1 in the supplementary material presents the data mentioned here by gender and age.

Table S1. Data used to calculate CO_2 emissions from human breathing. The population distribution is exclusive for Frankel district. Weight distribution and labour force participation rates are Singapore-wide averages. School and work hours by age were determined from official schedules and local experience.

Age range (years)	Breathing rate[1] (min^{-1})	Population distribution (%)[2]	Weight women (kg)[3,4,5]	Weight men (kg)[3,4,5]	Labour force rate women[6,7] (%)	Labour force rate men[6,7] (%)	School & work hours
0-4	29	4.7	9.42	10.07	50.0	50.0	8:30–13:30
5-9	22.6	5.5	22.68	23.57	100.0	100.0	7:30–14:00
10-14	17.8	6.2	39.48	41.46	100.0	100.0	7:30–15:00
15-19	15	7.0	48.37	57.46	100.0	100.0	7:30–16:00
20-24	15	6.3	54.08	69.14	80.0	85.0	7:00–19:00
25-29	15	5.7	54..08	69.14	85.7	93.3	7:00–19:00
30-34	15	6.8	58.12	69.22	81.3	97.7	7:00–19:00
35-39	15	8.8	58.12	69.22	75.2	98.0	7:00–19:00
40-44	15	7.9	58.12	69.22	72.7	96.8	7:00-19:00
45-49	15	8.2	58.12	69.22	68.9	96.1	7:00–19:00
50-54	15	7.8	58.12	69.22	64.9	92.6	7:00–19:00
55-59	15	6.9	58.12	69.22	51.7	85.0	7:00–19:00
60-64	15	6.0	58.07	63.34	35.4	67.5	7:00–19:00
> 65	15	12.2	58.07	63.34	10.3	26.4	7:00–19:00

[1]Sherwood, L. 2006.
[2]Singapore Department of Statistics, 2011
[3]Health Promotion Board, 2004
[4]School Health Service, 1993
[5]National Healthcare Group Polyclinics, 2000
[6]Ministry of Manpower, 2011
[7]School hours for individuals below 20 years

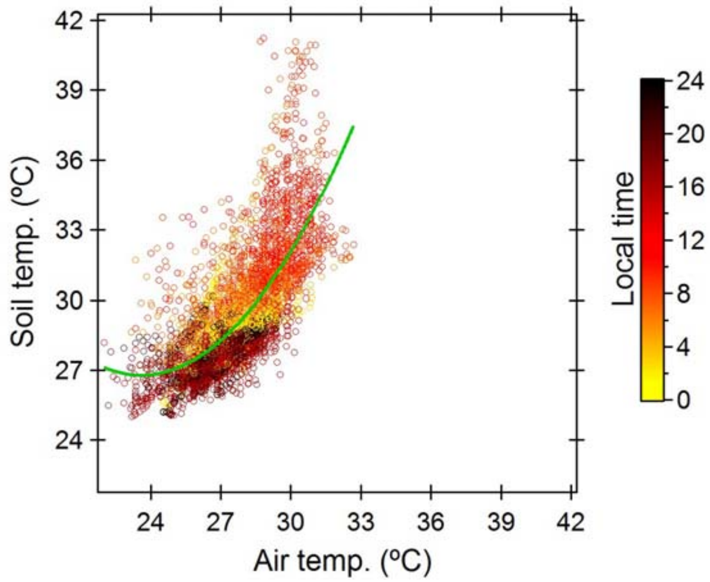

Figure S11.Correlation between soil (T_S) and air temperature (T_a). Polynomial regression (green curve): $T_S = 0.13T_a^2 – 6.12\ T_a + 99.04$, $r^2 = 0.55$. Data points are 30-min averages measured between February and June 2012 by a sensor (HMP45C; Vaisala) operated near the top of the EC mast and a rugged soil temperature sensor (RT-1; Decagon) installed at a depth of 2 cm.

Table S2. Average characteristics ±1 standard deviation of the fifteen most abundant species of woody trees in Telok Kurau. The data is based on 1,034 woody trees within a 350-m radius domain. WSD - wood specific density, *D* - diameter at breast height, AGB – aboveground dry biomass (boles and branches), RB - root biomass, LB – leaf biomass.

	Tree species	**Common name**	**Fraction (%)**	**Height (m)**	**WSD ($g\ cm^{-3}$)**	***D* (cm)**	**Total Biomass[1] ($ton\ tree^{-1}$)**	**Dry biomass distribution[2] (%)**	**CO_2 stored ($ton\ tree^{-1}$)**	**CO_2 annual sequestration ($kg\ tree^{-1}$)**
1	*Xanthostemon chrysanthus*	Golden penda	17.61	4.7±1.5	1.15[3]	7.6±6.7	0.16±0.85	AGB: 77.0 RB: 20.6 LB: 2.4	0.30±1.57	14.76±57.74
2	*Mangifera indica*	Mango tree	10.92	7.5±2.1	0.47[4]	37.1±21.4	1.89±3.59	AGB: 81.2 RB: 16.6 LB: 2.2	3.47±6.59	122.16±158.01
3	*Caesalpinia ferrea*	Pau ferro or brazilian ironwood	10.64	4.0±1.3	1.00[5]	8.4±6.4	0.15±0.56	AGB: 76.6 RB: 20.7 LB: 2.7	0.27±1.03	13.87±41.48
4	*Michelia champaca*	Champaca or champak	10.64	4.6±1.5	0.55[3]	9.5±8.9	0.15±0.59	AGB: 74.6 RB: 20.7 LB: 4.7	0.27±1.08	12.35±38.96
5	*Swietenia macrophylla*	Big-leaf mahogany	10.45	9.8±2.5	0.53[5]	46.6±19.4	3.04±2.98	AGB: 82.2 RB: 16.1 LB: 1.7	5.57±5.47	195.31±157.32
6	*Terminalia mantaly*	Madagascar almond	5.74	6.8±1.8	0.73[5]	16.3±7.0	0.31±0.34	AGB: 78.3 RB: 18.9 LB: 2.8	0.57±0.61	30.05±28.19
7	*Callistemon citrinus*	Bottlebrush	5.27	6.7±1.5	0.64[3]	24.9±9.8	0.76±0.69	AGB: 80.5 RB: 17.3 LB: 2.1	1.40±1.26	64.21±50.01
8	*Plumeria species*	Frangipani	4.99	3.5±1.6	0.51[5]	13.7±13.6	0.36±1.70	AGB: 75.0 RB: 20.2 LB: 4.7	0.69±3.20	25.17±88.44
9	*Khaya senegalensis*	African mahogany	3.01	10.6±4.2	0.76[3]	47.3±31.0	6.03±8.14	AGB: 82.3 RB: 16.3 LB: 1.4	11.07±15.14	342±395

10	*Peltophorum pterocarpum*	Yellow flame	1.69	11.2±2.2	0.74[5]	50.7±22.0	5.19±5.24	AGB: 83.3 RB: 15.5 LB: 1.1	9.53±9.61	321.83±262.00
11	*Bauhinia purpurea*	Hong Kong orchid	1.51	5.8±1.7	0.61[5]	19.2±10.9	0.47±0.58	AGB: 78.8 RB: 18.4 LB: 2.9	0.86±1.07	40.53±45.08
12	*Erythrina fusca*	Purple coral tree	1.41	4.0±0.5	0.28[6]	11.6±3.9	0.46±0.48	AGB: 74.0 RB: 19.2 LB: 6.8	0.85±0.88	5.19±4.47
13	*Lagerstroemia speciosa*	Pride of India	1.41	4.8±1.27	0.67[3]	14.1±7.1	0.21±0.23	AGB: 78.0 RB: 18.9 LB: 3.0	0.39±0.43	21.2±21.2
14	*Hopea odorata*	Takian or white thingan	1.32	4.9±2.6	0.62[4]	16.4±17.9	0.68±1.32	AGB: 73.7 RB: 21.8 LB: 4.5	1.26±2.42	50.53±89.49
15	*Lagerstroemia floribunda*	Crape myrtle	1.13	5.6±0.8	0.83[5]	16.4±1.9	0.30±0.22	AGB: 79.7 RB: 18.2 LB: 2.1	0.55±0.40	30.91±19.59

[1]Total biomass = AGB + RB + LB

[2]AGB was calculated from eq. (3) using specific WSD values by species for each inventoried tree. RB and LB were calculated from eqs. (4) and (5), respectively.

[3]World Agroforestry Centre (2004).

[4]Suzuki (1999).

[5]Chave et al. (2006).

[6]Wishnie et al. (2007).

Table S3. Average characteristics ±1 standard deviation of the fourteen species of palm trees identified in Telok Kurau. The data is based on all inventoried trees within a 500-m radius domain. *D* - diameter at breast height.

	Tree species	**Common name**	**Fraction (%)**	**Height[1] (m)**	***D* (cm)**	**Total dry biomass[2] (kg tree^{-1})**	**CO_2 stored (kg tree^{-1})**	**Growth rate (cm year^{-1})**	**CO_2 annual sequestration (kg tree^{-1})**
1	*Adonidia merrilli*[3]	Manila palm	42.21	2.75±1.01	13.41±2.53	33.49±9.84	51.62±15.17	*Euterpe precatoria* eq.[8]	5.05±1.49
2	*Areca catechu*[4]	Areca nut palm	11.37	3.76±2.22	10.05±2.82	44.00±27.49	67.83±42.38	*Euterpe precatoria* eq.[8]	7.60±2.58
3	*Wodyetia bifurcata*[5]	Foxtail palm	9.00	2.55±1.17	14.75±5.07	69.95±38.81	107.82±59.82	10.5[9]	6.01±1.03
4	*Livistona chinensis*[6]	Chinese fan	5.75	3.18±1.74	17.23±2.33	61.51±48.09	94.82±48.09	*Euterpe precatoria* eq.[8]	8.32±5.70
5	*Cocos nucifera*[5]	Coconut palm	5.24	4.17±2.14	18.03±2.42	124.81±63.04	192.38±97.17	125 ($h < 5.5$ m) 40 ($h > 5.5$ m)[10]	51.47±15.94
6	*Not identified*[3]	Generic palm	4.53	2.73±2.00	15.06±5.28	33.30±19.38	51.32±29.87	*Euterpe precatoria* eq.[8]	4.68±2.90
7	*Coccothrinax argentata*[6]	Silver palm	4.34	4.84±3.53	18.54±3.53	97.34±68.28	150.04±105.24	*Euterpe precatoria* eq.[8]	14.03±11.63
8	*Roystonea oleracea*[5]	Caribbean royal palm	4.21	3.65±1.80	19.37±9.11	105.84±56.90	163.15±87.70	10.5[9]	5.89±1.33
9	*Ravenala madagascariensis*[3]	Traveller's tree	3.96	1.60±1.46	18.42±3.22	22.35±14.21	34.45±21.90	*Euterpe precatoria* eq.[8]	2.97±2.44
10	*Phoenix dactylifera*[7]	Date palm	2.68	3.59±1.57	20.70±1.53	159.00±67.74	245.08±104.42	20.8[12]	16.58±0.00
11	*Elaeis guineensis*[7]	Oil palm	2.55	2.93±0.79	36.45±2.59	130.54±34.01	201.22±52.42	45[11]	176.32±8.20
12	*Licuala grandis*[4]	Ruffled fan palm	1.79	1.36±0.60	10.39±4.98	12.91±8.61	19.91±13.26	*Euterpe precatoria* eq.[8]	3.99±1.61
13	*Phoenix Roebelenii*[4]	Pygmy date palm	1.02	1.44±0.59	12.40±4.14	14.05±8.48	21.66±13.07	20.8[12]	5.47±0.11
14	*Latania lontaroides*[6]	Red latan palm	0.83	4.60±1.63	16.04±1.89	81.89±27.79	126.22±42.84	*Euterpe precatoria* eq.[8]	13.47±6.12
15	*Bismarckia nobilis*[6]	Bismarck palm	0.51	4.25±2.67	23.87±8.72	80.38±42.14	123.91±64.95	*Euterpe precatoria* eq.[8]	12.55±9.66

[1]Crownshaft and crown are excluded from estimating the height.
[2]A factor of 1.15 is applied to the total aboveground dry biomass (AGB) to account for the root biomass (Janssens et al. 2003) with the exception of palms whose total biomass is estimated from the *Prestoea montana* equation.
[3]Biomass estimated from *Prestoea montana* eq. ($Total\ Biomass = 9.7h + 6.8$; Frangi and Lugo, 1985).
[4]Biomass estimated from *Euterpe precatoria* eq. ($Total\ AGB = 6.666 + 12.826h^{1/2} \ln h$; IPCC, 2003).
[5]Biomass estimated from *Attalea phalerata* eq. ($Total\ AGB = 23.487 + 41.851(\ln h)^2$; IPCC, 2003).
[6]Biomass estimated from *Sabal sp.* eq. ($Total\ AGB = 24.559 + 4.921h + 1.017h^2$; IPCC, 2003).
[7]Biomass estimated from *Elaeis guineensis* eq. ($Total\ AGB = 37.47h + 3.6334$; Thenkabail, 2004).
[8]$h_{growth} = -3182.4 + 3239.3\exp(-(((h - 914.9) / 6860.1)^2))$, h_{growth} in cm year^{-1} and h in cm (Homeier et al., 2002).
[9]Zona (1996).
[10]In urban landscapes coconut palms reach a height of 4.5 – 5.5 m at an age of 3 – 4 years. Thereafter height growth moderates to 30 – 50 cm year^{-1}. Annual yields range from 15 – 20 kg per palm (Chan and Elevitch, 2006). We consider an annual yield of 17.5 kg for all trees over 5.5 m of height.
[11]Oil palms grow 0.3 – 0.6 m year^{-1}. From observations in Malaysia's oil palm plantations, 91.80 and 3.69 kg year^{-1} of new dry biomass is associated with leaves and root growth, respectively (Corley and Tinker, 2003). We consider that palms are on vegetative stage. Flowers and bunches will add 4.09 and 109.02 kg year^{-1} of dry biomass, respectively.
[12]Broschat(1998).

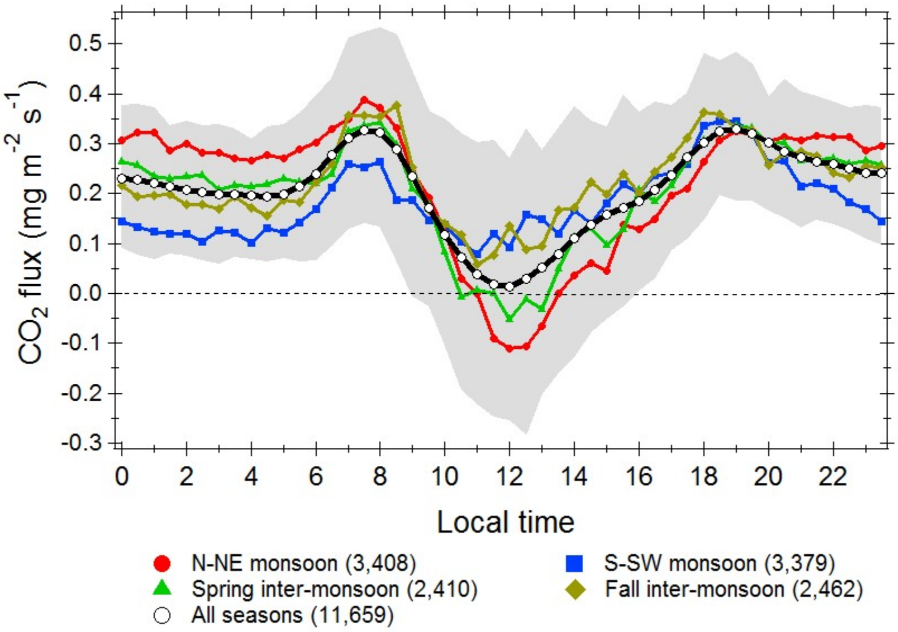

Figure S12. Diurnal variability of CO_2 fluxes measured by EC according to monsoon season. The average diurnal profile for each season is within ±1 standard deviation of the all seasons average (grey shaded area). Spring (fall) inter-monsoon covers the transition period between the N-NE and S-SW (S-SW and N-NE) monsoons. Numbers in parenthesis are 30-min periods used after data quality control.

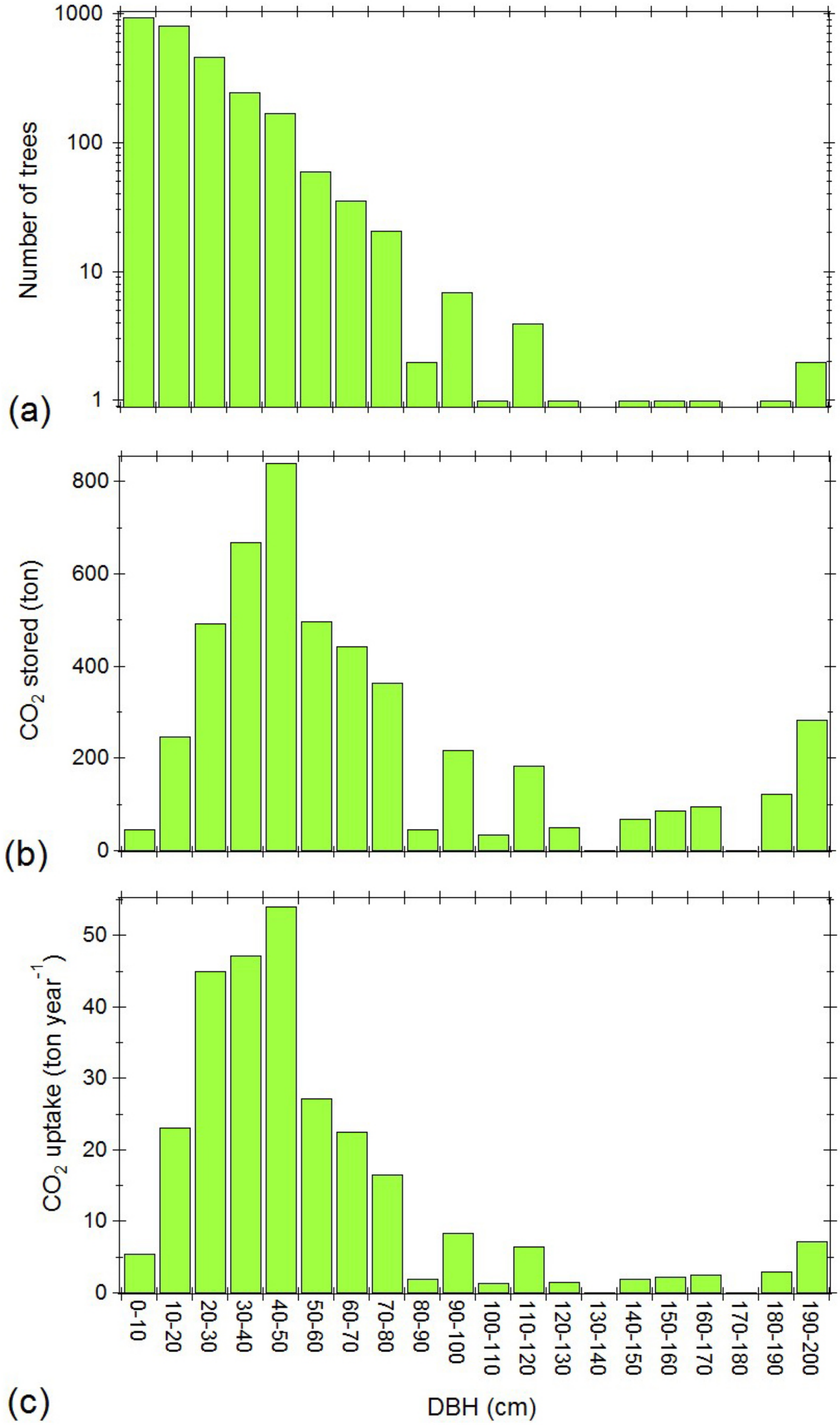

Figure S13. (a) Number of trees, (b) CO_2 stored and (c) CO_2 sequestered within a 500 m radius domain centered on the EC tower. Small trees (i.e. D < 20 cm) account for a larger number of woody trees in Telok Kurau. However, large trees represent the major CO_2 storage and dominate the CO_2 sequestration. Even though the number of trees with a D > 100 cm is small (12), they store 19.5% of the total CO_2 and contribute 9.6% to the annual sequestration. The annual biomass production was calculated using the allometric equations for primary and secondary tropical moist forests given by Chave et al. (2005) and van Breugel et al. (2011), respectively and the metabolic theory of ecology with scaling parameters depending on tree D (i.e. small and large).

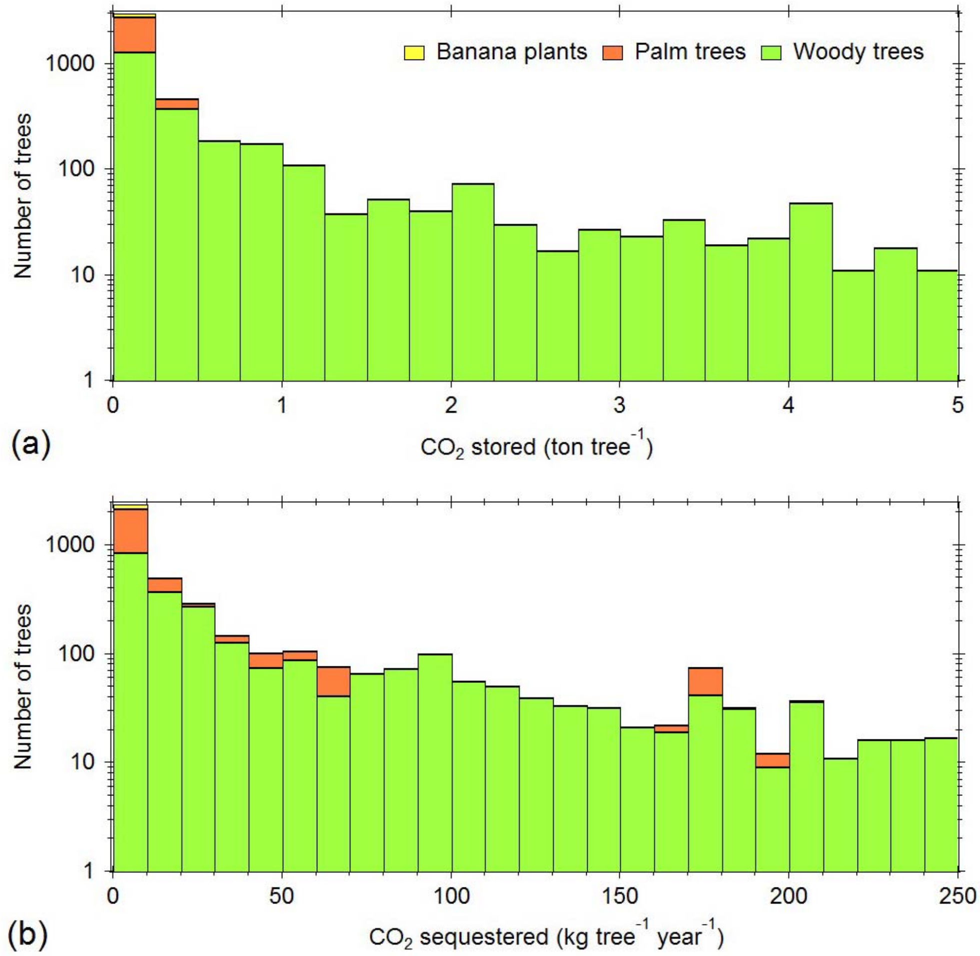

Figure S14. Number of tress as function of (a) CO_2 stored and (b) CO_2 sequestered. The majority of trees in Telok Kurau store and sequester less than 250 kg and 20 kg year^{-1}of CO_2, respectively. As explained in the main text, the CO_2 storage and sequestration are dominated by large trees. The contribution of other herbaceous plants not included in this study must have contributions similar to or smaller than those observed for banana plants.

References

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