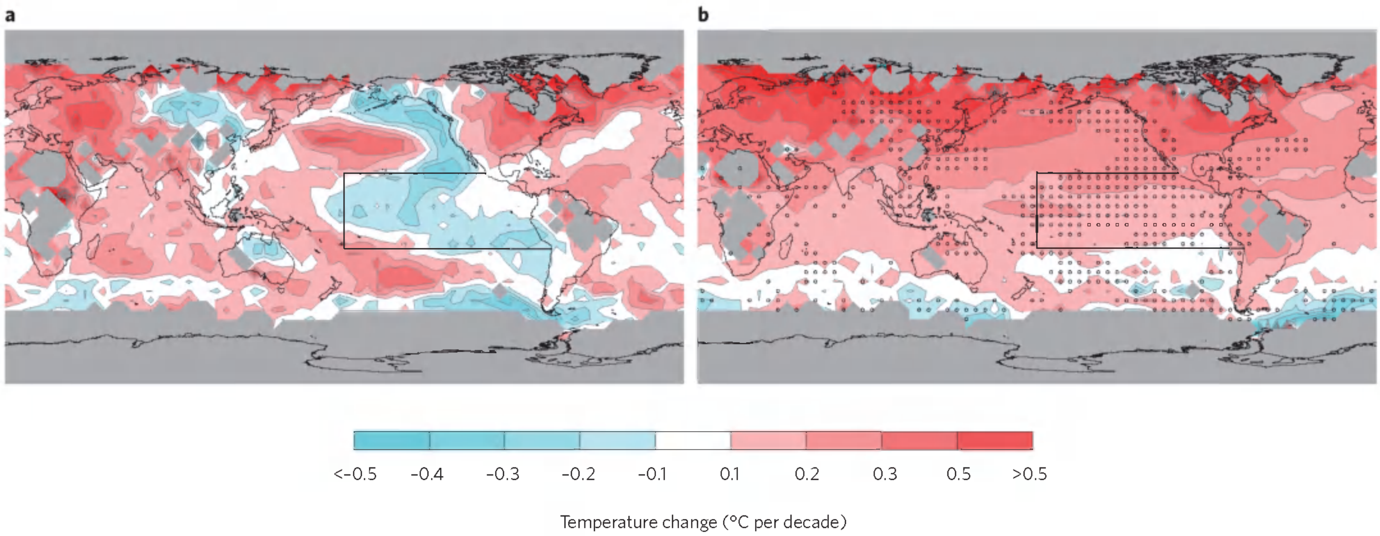

Figure 2 | Trends in global surface temperature for 1993–2012. **a**, Observed trends. **b**, Average simulated trends from 117 simulations of the climate by 37 CMIP5 models. As in Fyfe *et al.*[1] the simulations are sampled only where corresponding observations exist. Trends are computed only at grid points with at least 50% temporal coverage. The rectangles encompass the eastern tropical Pacific region[2]. In **b** the stippling indicates where the observed trends are outside the 5–95% range of the simulated trends.

models underestimate the probability of large internally generated cooling trends in this region. We further note that the models simulate externally forced warming in this region since about 1970 (Supplementary Fig. 1), which is likely to be associated in part with simulated weakening of the Walker circulation[5–7], whereas observed sea surface temperatures cooled and the Walker circulation strengthened over the past 20 years[2,5].

In conclusion, we agree with Kosaka and Xie[2] that accounting for cooling in the eastern tropical Pacific could, in principle, reconcile recent observed and simulated global warming. However, based on the CMIP5 ensemble of climate simulations, the probability of simulating the recently observed eastern tropical Pacific cooling with a freely running climate model under the CMIP5 radiative forcing protocol is very low, and hence so too is the probability of simulating the observed global temperature change over the past 20 years. ❐

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Author contributions
J.C.F. carried out most of the analysis and wrote the initial draft. N.P.G. helped with the analysis and edited the paper.

Additional information
Supplementary Information is available in the online version of the paper.

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CORRESPONDENCE:

Palm oil wastewater methane emissions and bioenergy potential

To the Editor — Palm oil production is driving economic growth, rural development and poverty alleviation in many equatorial economies, yet often with loss of tropical forests[1]. Here we show that the climate threats do not end following forest clearing: methane (CH_4) emissions from palm oil wastewater effluent, known as POME[2], represent a significant and rising source of atmospheric warming.

A typical wastewater facility emits around 3,288 tCH_4 yr^{-1}, equating to 111,804 tCO_2e yr^{-1} because of the greater global warming potential of CH_4 (Supplementary Tables 1–3 and Excel database) — comparable to the annual emissions of ~22,000 passenger vehicles in the United States[3]. This year, emissions will reach ~135 $MtCO_2e\ yr^{-1}$ pantropically (Fig. 1), equal to over 30% of Indonesian fossil fuel emissions[4]. Projections of industry growth[5] suggest emissions could rise to 0.363 gigatons of $CO_2e\ yr^{-1}$ by 2050, which is roughly 12% of gross carbon emissions from tropical deforestation[6], or 1% of current global greenhouse gas emissions from fossil fuel and cement production[4] — a large climate impact that remains insufficiently addressed within the public debate over the sustainability of the industry.

To be clear, forest destruction, especially on peatlands, dwarfs the climate impact of POME CH_4 emissions. On an areal basis, POME releases 7 $tCO_2e\ ha^{-2}\ yr^{-1}$ compared with 86 $tCO_2e\ ha^{-2}\ yr^{-1}$ from peat decomposition[7] (Supplementary Table 1 and Excel database). However, the inevitable shift towards agricultural intensification will increase the importance of POME CH_4 in the future. POME CH_4 is well suited for bioenergy production, and presents a potential win–win for climate mitigation and renewable energy production[2]. A typical biogas power plant can produce over 15,000 MWh yr^{-1} — equivalent to the demand of ~30,000 households in Indonesia. In 2013 alone, nearly 24 million MWh of potential electricity was unused (Fig. 1), which is one fourth of Malaysia's current energy consumption[4]. A variety of biogas technologies are already mature[2] (Supplementary Fig. 1), but less than 5% of mills globally have tapped this resource. Why?

Palm oil mills already use other biomass waste streams for energy[2], and grid connection is often prohibitively expensive in remote areas of Malaysia and Indonesia, where most mills are located. Alongside grid expansion, governmental policies are needed that reduce project risks and increase economic incentives. For example, Thailand has established a secure power purchase process and attractive off-take tariffs[8]; 48 of 72 palm oil mills now generate POME bioenergy. Also, Malaysia has launched a national economic transformation programme that prioritizes biogas implementation to reduce greenhouse gas emissions and promote renewable energy (http://etp.pemandu.gov.my/). Infrastructure development will take time, and for mills without access to the grid there are immediate ways to mitigate POME CH_4.

POME CH_4 emissions can be captured to generate certified emission reductions (CERs) via the United Nation's Clean Development Mechanism (CDM; http://cdm.unfccc.int/). The CDM was a major stimulus for biogas in the 2000s, but an oversupply of carbon credits has devalued CERs and stalled investments for the foreseeable future[9]. POME can also be used as fertilizer and other derivative products, though more research is needed to determine best management practices and cost effective applications[10]. All of these mitigation strategies face the broader challenge of being generally far less profitable than competing business investments such as land banking, boosting yields or replanting.

International consumer markets could provide additional leverage. The Roundtable for Sustainable Palm Oil (www.rspo.org) has pioneered a comprehensive strategy to make sustainable palm oil the norm. Already, member producers are encouraged to capture biogas (Principles and Criteria 5.4 and 7.8; http://go.nature.com/PqVREj) and will be required to in the future. The RSPO currently certifies 15% of market volume, and now the onus is on buyers to consume sustainable palm oil, which would in turn drive POME CH_4 abatement.

Though POME CH_4 mitigation would not remove the damages of forest clearing, it has co-benefits for mill owners, local communities and those broadly impacted by climate change. Crucially, the financial benefits from POME bioenergy must be coupled to a strict moratorium on forest clearing to prevent the financing of deforestation, which would overwhelm the climate benefits of POME CH_4 bioenergy. Progress on both fronts is slow, but direly needed if palm oil is to fully achieve its promise of social, environmental and economic prosperity. ❐

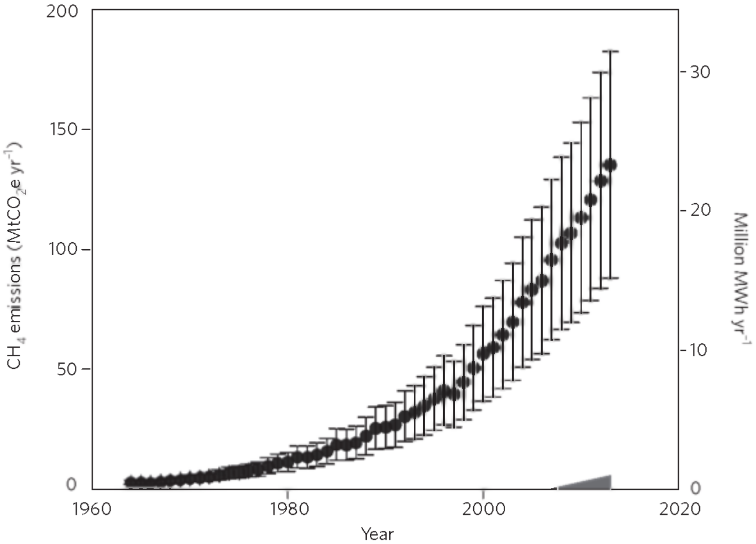

Figure 1 | Methane emissions from palm oil wastewater are an untapped bioenergy resource. Global scale CH_4 emissions and electricity potential were calculated by applying CH_4 emission and energy scaling factors to palm oil production statistics (Supplementary Tables 1–4 and Excel database). Error bars reflect the uncertainty in CH_4 emissions at 95% confidence intervals based on potential variation in wastewater treatment conditions at mills throughout the tropics (Supplementary Table 4). We estimate that 5% of mills capture POME bioenergy pantropically (shaded portion).

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Additional information

Supplementary Information is available in the online version of the paper.

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