ORIGINAL PAPER



Dematerialization Through Services: Evaluating the Evidence

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Received: 8 November 2018 / Accepted: 22 February 2019 © Springer Nature Switzerland AG 2019

Abstract

Dematerialization through services is a popular proposal for reducing environmental impact. The idea is that by shifting from the production of goods to the provision of services, a society can reduce its material demands. But do societies with a larger service sector actually dematerialize? I test the 'dematerialization through services' hypothesis with a focus on fossil fuel consumption and carbon emissions—the primary drivers of climate change. I find no evidence that a service transition leads to carbon dematerialization. Instead, a larger service sector is associated with *greater* use of fossil fuels and *greater* carbon emissions per person. This suggests that 'dematerialization through services' is not a valid sustainability policy.

Keywords Dematerialization · Service transition · Carbon emissions · Energy

Introduction

'Dematerialization through services' (Heiskanen and Jalas 2000) is a popular proposal for reducing environmental impact. The idea is that by shifting from producing goods to providing services, a society can reduce its use of materials. But do societies with a larger service sector actually dematerialize? I test the 'dematerialization through services' hypothesis with a focus on fossil fuel use and carbon emissions — the primary drivers of climate change. I ask: does a service transition lead to fossil fuel and/or carbon emissions dematerialization?

Using international data from the World Bank, I test for both relative and absolute carbon dematerialization through services. Over the long term, I find that a service transition leads to an *increase* in the carbon intensity of GDP. Similarly, I find that a service transition leads to *increasing* carbon emissions per capita. This finding echos Jevons' paradox. Jevons (1906) found that the adoption of more energy-efficient technology led to *greater* (not lesser) energy use (Alcott 2005; Polimeni et al. 2012). Like more efficient technology, the service sector can supposedly do more with less. It generates more value added per unit of direct energy input. Yet a service transition produces the opposite of its intended effect. The relative growth of the service sector is

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associated with *greater* energy use (and hence greater emissions). The reasons why this occurs are likely complex, but the implications are simple. The evidence indicates that 'dematerialization through services' is not a valid sustainability policy.

This paper is laid out as follows: "Dematerialization Through Services: The Rationale" discusses the rationale behind the 'dematerialization through services' proposal. "Methods outlines methods" and section "Results discusses results. "Discussion" discusses reasons why the 'dematerialization through services' proposal fails. Section "Conclusions:" concludes with thoughts on the significance of this evidence, and what it means for sustainability policy.

Dematerialization Through Services: The Rationale

The 'dematerialization through services' proposal begins with an uncontentious observation. In terms of direct energy use, the service sector is less energy intensive than industrial sectors like mining, manufacturing, and construction. For instance, the US service sector is about three to four times less energy intensive than US industry (Fig. 1).

Proponents of the 'dematerialization through services' hypothesis take this uncontentious observation, and go one step further. Because of the lower direct resource intensity of the service sector, they propose that a "transition from an industrial to a service society might bring about a decline in





Fig. 1 Comparing the direct energy intensity of US sectors. This figure compares the direct energy intensity of US industry and US services. 'Industry' consists of mining, manufacturing, construction and utilities. 'Services' consist of all other non-industrial sectors (except

agriculture). Panel **a** shows the energy intensity of value added for US industry and US services over the years 1997 to 2017. Panel **b** shows energy use per worker for US industry and US services over the years 1998 to 2016. For sources and methods, see the Appendix

the use of materials" (Herman et al. 1990). A non-exhaustive list of authors who have echoed this proposal would include Cooper (1999), Hawken (2000), Herman et al. (1990), Hinterberger and Schmidt-Bleek (1999), Jackson (1996), Kahn (1979), Lovins et al. (1999), OECD (2000), Panayotou et al. (2000), Romm et al. (1999), Romm (2002), Stahel (1997), Victor (2010), and White et al. (1999). For a good review of the literature on this topic, see Heiskanen and Jalas (2000) and Heiskanen et al. (2001).

While based on plausible reasoning, the 'dematerialization through services' proposal has many critics. Djellal and Gallouj (2016), Jespersen (1999), and Lawn (2001) have all argued that it is wrong to treat the service sector as a separate entity from industry. Instead, they argue that services are intrinsically connected to the production of goods (and vice versa). For instance, a car dealership (a service) depends on the production of cars for its existence. Likewise, the car manufacturer depends on the dealership to sell its product. The service sector cannot and does not operate in isolation (Giampietro et al. 2012; Hall and Klitgaard 2012). One way to capture this interdependence is to measure both direct and indirect energy use. Jesperson (1999) finds that when *indirect* energy use is included, the Danish private service sector has an energy intensity similar to the manufacturing sector.

Kander (2005) identifies a more subtle problem. The growth of the service sector's share of value added is affected by price change. The problem is that service sector prices tend to rise faster than the price of goods. This means that using 'nominal' prices can inflate the growth of the service sector. When 'real' prices are used, there is less

evidence for dematerialization through services (Henriques and Kander 2010).

Another problem, is that the transition to services could increase transport volumes (Ellger and Scheiner 1997). Amazon.com's business model is a good example. Greater transportation volume could nullify any dematerialization that might otherwise occur.

There is also the problem of open borders. Western countries that are deindustrializing are not doing so in isolation. Instead, they are off-shoring many of their industrial processes to developing countries. Davis and Caldeira (2010) find that the US and Western Europe have significant net CO_2 emissions embodied in trade. Similarly, Knight and Schor (2014) find that evidence for emissions-GDP decoupling disappears when they account for the emissions embodied in trade. This means we should be skeptical of dematerialization claims that do not account for trade effects (Stern et al. 1996; Day et al. 2014).

But perhaps, the most damning critique of 'dematerialization through services' is that its proponents focus on *relative* rather than *absolute* dematerialization. Proponents tout the decreasing energy intensity of GDP. But this is a *relative* (i.e. intensive) metric that does not indicate the *scale* of energy use (Giampietro et al. 2012). Our impact on the biosphere depends on the scale of consumption, not the efficiency of this consumption (Ehrlich and Holdren 1971).

Giampietro et al. (2012) use the analogy of a mouse and an elephant to illustrate this point. A mouse has a metabolic rate of about 3 W/kg, while an elephant has a metabolic rate of about 0.5 W/kg. Clearly, the elephant is more efficient at

Absolute dematerialization	Relative dematerialization	
Fossil fuel use per capita	Fossil fuel intensity of GDP	
CO ₂ emissions per capita	CO ₂ intensity of GDP	
Service sector size		
Service sector share of employment		

Service sector share of value added

using energy. However, the elephant's total energy demand is about 50,000 times that of the mouse. Despite its greater efficiency, the elephant has a far greater impact on its environment. Likewise, a wealthy nation may generate more value added per unit of energy than a developing nation. But if the wealthy nation uses more non-renewable energy than the developing nation, its greater 'efficiency' is a moot point for sustainability purposes. Giampietro et al. do not mince words:

That modern neoclassical economists (and quite a few ecological economists) see elephants as dematerialized versions of mice would be a mere amusing finding, if it were not for the fact that this silly narrative is being taught to students in almost every academic programme dealing with the sustainability of human progress ... (Giampietro et al. 2012)

Similar critiques have been raised by Daly (2013), Hall and Klitgaard (2012), and Jackson (2009), among others. I take this critique seriously. Thus, I test for both relative and absolute dematerialization.

Methods

To test for dematerialization through services, I focus on fossil fuel use and CO₂ emissions. This gives a direct indicator of climate-change sustainability. I use four different metrics of dematerialization (Table 1). I define *relative* dematerialization as a decline in the fossil fuel and/or carbon intensity of GDP. I define *absolute* carbon dematerialization as a reduction in *per capita* carbon emissions and fossil fuel use (not total emissions and/or fossil fuel use). I use per capita data because I compare countries that have different populations. This removes the effects of population growth, which I regard as a separate sustainability issue from the growth of per capita consumption. Service sector size is measured using both employment share and value-added share (using current prices).¹ I test for a scaling relation between each dematerialization metric (*D*) and the service fraction (S_{frac}) of employment or value added:

$$D \propto S_{\text{frac}}^{\alpha}$$
 (1)

Equation (1) can be rewritten in terms of a log-log regression:

$$\log(D) \propto \alpha \cdot \log(S_{\text{frac}}) \tag{2}$$

The scaling-exponent α quantifies how the dematerialization metric *D* behaves as the service sector grows. A *negative* exponent indicates that the dematerialization metric *declines* as the service sector increases in size. This is evidence for dematerialization through services. A positive exponent indicates that the dematerialization metric *increases* as the service sector increases in size. This is evidence *against* dematerialization through services.

All data for this test comes from the World Bank and covers 217 countries over the years 1991 to 2017 (Table 2). This data is sufficient to conduct a robust test of dematerialization trends *between* countries. It also allows a more limited test for trends *within* countries. The short (30 year) time frame limits the ability to establish statistically significant trends within countries.

Results

Figures 2, 3, 4 and 5 show the results of my test for carbon dematerialization through services. Figures 2 tests for *absolute* dematerialization using trends *between* countries. Figure 3 tests for *absolute* dematerialization using trends *within* countries. Figure 4 tests for *relative* dematerialization using trends *between* countries. Lastly, Figure 5 tests for *relative* dematerialization using trends *within* countries. Results are summarized in Tables 3, 4, 5 and 6.

I find no evidence that a service transition leads to *absolute* carbon dematerialization. The between-country trends are clear (Fig. 2 and Table 3). A service transition is systematically associated with the *growth* of per capita fossil fuel use and carbon emissions. Within-country trends (Fig. 3 and Table 4) are also positive on average, but

¹ Why not measure service sector value added using 'real' prices? First, this data is not available from the World Bank database used here. Second, there are numerous problems with price deflation.

Footnote 1 (continued)

The main problem is that relative prices change over time, meaning the choice of base year will affect the resulting deflation (Fix 2015; Nitzan 1992; Nitzan and Bichler 2009). Kander (2005) highlights how this affects the calculation of the service sector's share of value added. This same problem also leads to systematic uncertainty in the calculation of real GDP. However, out of convention, I use standard measures of real GDP to test for relative dematerialization. But it is important to recognize that real GDP is not necessarily an objective measure of economic output (Fix 2019).

Table 2	World Bank Data
Series	

Series code	Description	
EG.EGY.PRIM.PP.KD	Energy intensity level of primary energy (MJ/\$2011 PPP GDP)	
EG.USE.COMM.FO.ZS	Fossil fuel energy consumption (% of total)	
EG.USE.PCAP.KG.OE	Energy use (kg of oil equivalent per capita)	
EN.ATM.CO2E.PC	CO ₂ emissions (metric tons per capita)	
EN.ATM.CO2E.PP.GD.KD	CO ₂ emissions (kg per 2011 PPP \$ of GDP)	
NV.SRV.TETC.ZS	Services, etc., value added (% of GDP)	
SL.AGR.EMPL.ZS	Employment in agriculture (% of total employment)	
SL.IND.EMPL.ZS	Employment in industry (% of total employment)	
SL.SRV.EMPL.ZS	Employment in services (% of total employment)	
SL.TLF.TOTL.IN	Labor force, total	
SP.POP.TOTL	Population, total	

with a smaller scaling exponent and weaker statistical significance. This weaker evidence is likely due to the short period covered by the within-country data. This allows statistical 'noise' to dominate the 'signal'. Still, the data is sufficient to draw conclusions. There is no evidence for a negative scaling exponent (on average) either between or within countries. Thus, this test does not support *absolute* dematerialization through services.

The evidence for *relative* dematerialization through services is less clear. Between-country evidence (Fig. 4 and Table 5) indicates that a service transition is associated with greater fossil fuel intensity and CO2 intensity of GDP. This relation is statistically significant when service sector size is measured using employment. It is not significant (at the 1% level) when service sector size is measured using value added. Since there is no evidence for a negative scaling exponent, the between-country data does not support *relative* dematerialization through services. However, the within-country evidence seems to contradict this finding (Fig. 5 and Table 6). Here, the average scaling relation is *negative*, but with weak statistical significance. The within-country data supports relative dematerialization through services, but contradicts the between-country evidence. I discuss the reason for this apparent contradiction in "Discussion" section.

To summarize, the evidence indicates that a service transition does not lead to *absolute* carbon dematerialization. Thus, we must conclude that a service transition does not lead to greater sustainability. The evidence for *relative* carbon dematerialization is less clear. While unimportant for sustainability, relative dematerialization is a popular concept among environmental economists. Thus, it is important to understand the cause of the contradictory evidence.

Discussion

Our test of dematerialization through services yielded two notable findings. First, the evidence for relative dematerialization was conflicting. Second, there was no evidence for absolute dematerialization through services. I discuss possible explanations for these findings below.

The Contradictory Evidence for Relative Carbon Dematerialization

Why does *between*-country evidence suggest that relative carbon dematerialization through services is a failure? Yet *within*-country evidence suggests that it is a success? The answer is that relative carbon dematerialization trends are likely *non-linear*. They have an inverted U shape over the long term.

To understand this behavior, we begin with the following relation:

$$\frac{E_{\rm FF}}{\rm GDP} = \frac{E_T}{\rm GDP} \cdot \frac{E_{\rm FF}}{E_T}$$
(3)

This equation states that the fossil fuel intensity of GDP $(E_{\rm FF}/{\rm GDP})$ is driven by the energy intensity of GDP $(E_T/{\rm GDP})$ and the fossil fuel fraction of total energy use $(E_{\rm FF}/E_T)$. We want to know the trends in the right-hand terms in Eq. (3).

Figure 6a shows *between*-country trends in the energy intensity of GDP versus service employment share. Figure 6b shows *within*-country trends for the same relation. A service transition is associated with a *decrease* in the energy intensity of GDP. This is often touted as evidence for relative dematerialization through services. However, we must account for the *type* of energy used. Figure 6c, d show that the fossil fuel energy fraction tends to *increase* with a service transition. This is evident both between countries (Fig. 6c) and within countries (Fig. 6d). Why









Fig. 2 Testing for absolute carbon dematerialization through services. This figure tests for *absolute* dematerialization through services using *between-country* evidence. Lines represent the path through time of countries over the years 1991–2017. All plots use log–log scales. R^2 values are for log–log regressions on *mean values* for each country. Grey regions indicate the 95% prediction interval of each regression. Panel **a** shows the relation between the fossil fuel intensity of

GDP (measured in \$2011 purchasing power parity) and service sector employment share. Panel **b** shows the relation between the CO_2 intensity of GDP and service sector employment share. Panels **c** and **d** keep the same *y*-axis as **a** and **b** (respectively), but measure service sector size using percentage of total value added. All data comes from the World Bank (Table 2)

does this positive relation exist? Likely because a service transition is a basic part of industrialization. And the latter involves transitioning to fossil fuels (Hall and Klitgaard 2012; Smil 2008).

To summarize, the energy intensity of GDP tends to *decrease* with a service transition. In contrast, the fossil fuel energy fraction tends to *increase*. These opposing trends explain the *between*-country relative dematerialization evidence (Fig. 4). Over the long term, the increasing fossil fuel fraction drowns out the decreasing energy intensity of GDP. Since *between*-country analysis is sensitive

to long-term trends, we find that the fossil fuel intensity of GDP increases with a service transition.

When we use *within*-country data (Fig. 5), we measure short-term trends. This is because the World Bank data covers less than 30 years. Over this period, within-country data indicates that the fossil fuel intensity of GDP *decreases* with a service transition. This contradictory trend is caused by non-linear behavior in the fossil fuel energy fraction. When countries industrialize, they undergo an energy transition to fossil fuels. But this energy transition eventually reaches fixation—usually when 80% to 90% of energy comes from

Т

0

0.3

0.2

0.1

0.0

_4

B CO2 Emissions per Capita vs. Service Employment

mean = 0.9







Fig. 3 Relative carbon dematerialization through services—withincountry evidence. This figure tests for *absolute* dematerialization through services using *within-country* evidence. Histograms show the distribution of within-country scaling exponents α (see Eqs. 1 and 2) over the years 1991 to 2017. Vertical lines indicate the mean withincountry exponent. Panel **a** shows the relation between the fossil fuel

D CO2 Emissions per Capita vs. Service Value Added

Δ

Within-Country Scaling Exponent (α)

12



intensity of GDP (measured in \$2011 purchasing power parity) and service sector employment share. Panel **b** shows the relation between the CO₂ intensity of GDP and service sector employment share. Panels **c**, **d** are similar to **a** and **b**, but measure service sector size using percentage of total value added. All data comes from the World Bank (Table 2)

fossil fuels. As a result, the fossil fuel fraction has a nonlinear relation with service sector size.

Figure 7a, b illustrate this behavior. Figure 7a shows within-country trends between the fossil fuel energy fraction and service employment share. Each boxplot represents the distribution of the scaling exponent (α) for a log–log regression (see Eqs. 1 and 2). Results are disaggregated by service sector size. We see a clear downward trend as the service sector grows. In countries with a small service sector (less than 50% of employment), the fossil fuel fraction *increases* with a service transition. But in countries with a large service sector (greater than 50% of employment), the fossil fuel fraction increases for (less than 50% of employment) and the service sector (greater than 50% of employment).

is also evident in the US (Fig. 7b). From 1800 to 1920, the fossil fuel fraction increased as the service sector grew. But after 1920, the fossil fuel fraction plateaued—corresponding to a service sector employment share of roughly 40%.

This non-linearity causes an inverted U-shaped relation between the fossil fuel intensity of GDP and service sector size. When the service sector is small, the fossil fuel fraction grows rapidly. This trumps the secular decline in the energy intensity of GDP. The result is an *increase* in the fossil fuel intensity of GDP with a service transition. But when the fossil fuel transition is complete, the declining energy intensity of GDP dominates the trend. This causes



Fig. 4 Relative carbon dematerialization through services—betweencountry evidence. This figure tests for *relative* dematerialization through services using *between-country* evidence. Lines represent the path through time of countries over the years 1991 to 2017. All plots use log–log scales. R^2 values are for log–log regressions on *mean values* for each country. Grey regions indicate the 95% prediction interval of each regression. Panel **a** shows the relation between the fossil

fuel intensity of GDP (measured in \$2011 purchasing power parity) and service sector employment share. Panel **b** shows the relation between the CO₂ intensity of GDP and service sector employment share. Panels **c** and **d** keep the same *y*-axis as **a** and **b** (respectively), but measure service sector size using percentage of total value added. All data comes from the World Bank (Table 2)

the fossil fuel intensity of GDP to *decrease* with further service growth.

Figure 7c, d illustrate this inverted U-shaped behavior. Figure 7c shows within-country trends between the fossil fuel intensity of GDP and service employment share. Each boxplot represents the distribution of the scaling exponent (α) for a log–log regression (see Eqs. 1 and 2). Results are disaggregated by service sector size. The relation is positive when the service sector is small. This means a service transition leads to *greater* fossil fuel intensity of GDP. But the relation becomes negative when the service sector is large. This means a continued service transition leads to *lesser* fossil fuel intensity of GDP

If we had access to long-term trends for each individual country, they would likely look like those of the United States (Fig. 7b). From 1800 to 1920, the fossil fuel intensity of US GDP *increased* as the service sector grew. But after 1920, the fossil fuel intensity of US GDP *decreased* as the service sector grew. The change in behavior corresponds to the plateau of fossil fuel use (Fig. 7b).

Importantly, the downward part of the U does not fully reverse the upward part. This means that the long-term



Within-Country Scaling Exponent (α)

Fig. 5 Relative carbon dematerialization through services—withincountry evidence. This figure tests for *relative* dematerialization through services using *within-country* evidence. Histograms show the distribution of within-country scaling exponents α (see Eqs. 1 and 2) over the years 1991 to 2017. Vertical lines indicate the mean withincountry exponent. Panel **a** shows the relation between the fossil fuel





Within-Country Scaling Exponent (α)

intensity of GDP (measured in \$2011 purchasing power parity) and service sector employment share. Panel **b** shows the relation between the CO_2 intensity of GDP and service sector employment share. Panels **c**, **d** are similar to **a** and **d**, but measure service sector size using percentage of total value added. All data comes from the World Bank (Table 2)

Table 3	Absolute carbon
demater	ialization-between-
country	evidence

Regression	α	R^2	р
Fossil fuel use per capita versus service employment share	2.55	0.62	***
CO ₂ emissions per capita versus service employment share	2.21	0.64	***
Fossil fuel use per capita versus service value-added share	1.98	0.13	***
CO ₂ emissions per capita versus service value-added share	2.18	0.16	***

 $***p < 10^{-4}$

US trend is *positive*, even though the recent trend is *negative*. This explains our conflicting results in Figures 4 and 5. The *between*-country analysis captures snapshots of countries along the long-term upward trend. The *within*-country analysis captures recent trends. Evidently, most countries are now in the downward part of the U. However, this decrease in the fossil fuel intensity of GDP has not undone the large increases of the past.

Table 4Absolute carbondematerialization—within-	Regression	ā	$\bar{R^2}$	p	
country evidence	Fossil fuel use per capita versus service employment share	0.81	0.41	0.12	
	CO_2 emissions per capita versus service employment share	0.90	0.41	0.13	
	Fossil fuel use per capita versus service value-added share	0.50	0.36	0.11	
	CO ₂ emissions per capita versus service value-added share	0.56	0.31	0.17	
Table 5 Relative carbon					
dematerialization—between-	Regression	α	R^2	р	
country evidence	Fossil fuel intensity of GDP versus service employment share	0.59	0.17	***	
	CO_2 intensity of GDP versus service employment share	0.64	0.29	***	
	Fossil fuel intensity of GDP versus service value-added share	0.11	0.00	0.62	
	CO2 intensity of GDP versus service value-added share	0.40	0.03	0.02	
	***p<10 ⁻⁴				
Table 6 Relative carbon dematerialization—within-	Regression	ā	$\bar{R^2}$	p	
country evidence	Fossil fuel intensity of GDP versus service employment share	- 1.00	0.48	0.12	
	CO ₂ intensity of GDP versus service employment share	-0.87	0.42	0.13	
	Fossil fuel intensity of GDP versus service value-added share	- 1.37	0.41	0.10	
	CO2 intensity of GDP versus service value-added share	- 1.03	0.35	0.17	
	R^2 and a values are for log-log regressions, α is the slope of the regression (see Eq. 1 and 2).				

 K^{-} and p values are tor log–log regressions. α is the slope of the regression (see Eq. 1 and 2) *** $p < 10^{-4}$

 $\bar{\alpha}, \bar{R^2}$ and \bar{p} indicate the average within-country regression values

Judging the Success of Relative Carbon Dematerialization

The U shape in the fossil fuel intensity of GDP complicates the judgment of relative dematerialization through services. Our verdict depends on our choice of time scale. Is a services transition a *long-term* phenomena? If so, then relative carbon dematerialization through services is a failure. Or is a service transition a *recent* phenomena? If so, relative carbon dematerialization has some success.

Trends in the United States suggest that a service transition is a long-term process. (Fig. 8a). The employment share of the US service sector has grown continuously for over 200 years (other than a dip during the Civil War). What stands out in recent US history is not the growth of services, but the decline in *industrial* employment from 1970 onward. This is what many environmental economists think of as the 'service transition'—the replacement of industrial activity with service activity. The problem is that this deindustrialization trend is likely an artifact of global trade. The US is now a massive net importer of goods (Gierlinger and Krausmann 2012). This means that industrial employment is far smaller than it would be if all goods production happened domestically.

The only way to be sure that trade effects are not involved is to look at the *world* economy—the only closed economy on Earth. On the world scale, there is no hint of deindustrialization (Fig. 8b). Instead, the trends mirror the long-term behavior in the US. Agriculture employment is declining, service sector employment is increasing, and industrial employment is roughly constant. This suggests that a service transition is a long-term process in which service employment replaces agricultural employment.

Thus, to evaluate the 'dematerialization through services' hypothesis, we must give the most weight to long-term trends. On this front, the evidence is clear. Over the long term, a service transition does not lead to relative carbon dematerialization. And even if we are interested in short-term trends, we still have a problem. Relative carbon dematerialization has nothing to do with sustainability. Instead, it indicates how societies *value* economic activity in relation to carbon emissions. This valuation is an interesting *sociological* process that is worth studying. But it does not measure biophysical sustainability.

The Failure of Absolute Carbon Dematerialization

The failure of *absolute* carbon dematerialization through services is due to two factors. First, the fossil fuel energy fraction increases with service sector size (Fig. 6a, b). Second,







Fig. 6 Decomposing relative carbon dematerialization. This figure dissects the relative carbon dematerialization results in Figures 4 and 5. Panel **a** shows between-country trends in the energy intensity of GDP versus service sector employment share. Lines indicate the path through time of individual countries. Panel **b** shows the distribution of within-country trends. Results are for log-log regressions on the energy intensity of GDP versus service sector employment share (see Eqs. 1 and 2). Panel **c** shows between-country trends for the percent-

energy use per capita tends to increase with a service transition (Fig. 9). Given these two trends, it is unsurprising that absolute dematerialization through services fails.

What is surprising is the *pervasiveness* of the energyservices relation. A link between energy use and service employment is evident at many levels of analysis. It is evident for the *world* as a whole (Fig. 9a). This is important, because the world is a closed system, so we can be sure that trade effects are not at play (i.e., off-shoring pollutionintensive industry). A trend between energy use and service sector employment is evident *between* countries (Fig. 9b)





D Within-Country Scaling of



age of energy derived from fossil fuels versus service sector employment share. Panel **d** shows the distribution of within-country trends. Results are for log–log regressions on the fossil fuel energy fraction versus service sector employment share. **a** and **c** use log–log scales. R^2 values are for log-log regressions on national averages. Grey regions indicate the 95% prediction interval of each regression. All data for comes from the World Bank (Table 2)

and *within* countries (Fig. 9c). It is also evident over two centuries of US history (Fig. 9d).

An energy-service trend is also evident within US *industry*. Figure 9e plots energy use per worker in US industry against the employment share of *non-production workers* in industry. Non-production workers are employed by goodsproducing firms, but not directly involved with production (BLS 1957). These workers do *service-type* activity within industry. Evidently this service-type activity tends to grow as industrial energy use increases.

To summarize, an energy-services relation is evident at the global, international, national, and sectoral level.



Fig. 7 The plateau of the fossil fuel energy fraction and the U-shaped fossil fuel intensity of GDP. This figure shows how the evolution of the fossil fuel energy fraction leads to an inverted U-shaped relation between the fossil fuel intensity of GDP and service sector employment share. Panel **a** shows within-country trends between the fossil fuel energy fraction and service employment share. Boxplots show the distribution of scaling exponents (α) for log-log regressions (see Eqs. 1 and 2). The distribution of α is disaggregated by country's service sector size. Panel **b** shows US fossil fuel energy fractional service for the shows US fossil fuel energy fractional service sector size.

Moreover, this energy comes mostly from fossil fuels. As a result, a service transition is associated with greater carbon emissions.

Why is a Service Transition Associated With Greater Energy Use?

The increase of energy use with a service transition seems counter-intuitive. Compared to industry, the service sector uses far less direct energy per worker (Fig. 1). Yet the

tion versus service sector employment share. Panel **c** shows withincountry trends between the fossil fuel intensity of GDP and service sector employment share. Boxplots show the distribution of scaling exponents (α) for log-log regressions. The distribution of α is disaggregated by country's service sector size. Panel **d** shows the fossil fuel intensity of US GDP relative to service sector employment share. Data for **a** and **c** comes from the World Bank (Table 2). For US data sources and methods, see the Appendix

growth of service employment is strongly associated with the growth of energy use per capita. How can this be?

Jesper Jespersen points out a flaw in the 'dematerialization through services' reasoning. It assumes that a society can replace industrial activity with service activity, while leaving the structure of both sectors *unchanged*. But this is not what happens. Jespersen elaborates:

A significant and perhaps fundamental weakness of [the 'dematerialization through services' proposal] is that in the real economy (especially within the



Fig.8 Labor structure changes in the united states and the world. This figure shows historical changes in the three-sector labor structure of the United States economy (**a**) and the world economy (**b**). For

private sector) agriculture, manufacturing and services cannot be treated separately. Goods cannot be produced, sold and consumed without involving services related to business, finance, transport, the wholesale and retail trade, communication, waste processing and so on. In many respects, these activities are complements rather than substitutes. The point is that it is not possible just to switch between the manufacturing and service sectors because the indirect impact of changes in the altered manufacturing sector on the service sector is quite considerable. (Jespersen 1999)

In reality, a service transition is associated with a host of complex social changes. Most importantly, the growth of services is related to *economic growth*. This is an old idea, not a new discovery. More than 70 years ago Colin Clark argued that "the most important concomitant of economic progress" was "the movement of working population from agriculture to manufacture, and from manufacture to commerce and services" (Clark 1940). Proponents of 'dematerialization through services' have forgotten this idea. If a service transition is a key part of economic growth, it is easy to see why it fails to reduce emissions. Economic growth is overwhelmingly associated with increases in energy use (Brown et al. 2011, 2014).

To understand the link between economic growth, energy, and sectoral change, it is helpful to focus on labor productivity. Economists are nearly unanimous that economic growth involves increasing worker productivity. But what is often undiscussed is that increasing productivity generally requires



US data sources and methods, see the Appendix. World data comes from the World Bank (Table 2). World sector composition is calculated using national averages, weighted by national labor force size

greater energy use. Why? Productivity growth is typically achieved by augmenting human labor with machines. And these machines require energy to function. The laws of thermodynamics forbid otherwise. Thus, mechanization requires ramping up the energy used by machines. Not surprisingly, there is a strong relation between labor productivity and energy use (Cleveland et al. 1984; Hall et al. 1986; Fix 2015).

But how does the growth of productivity relate to a service transition? One possibility is that the service sector grows to consume the surplus produced in other sectors. Giampietro et al. credit George Zipf (1941) for first emphasizing consumption capacity:

Zipf proposed a basic principle of socio-economic development: if an economy wants to be able to produce more, it has to invest more in consuming. This principle implies that socio-economic development must be based on achieving an internal balance between parallel investments both of human activity and of energy over the two compartments of production and consumption ... (Giampietro et al. 2012)

Another possibility is that the service sector provides *facilitation* activity to other sectors (North 1990). Many services (such as accounting, logistics, education, etc.) are essential to goods production. It seems plausible that the demand for these services grows with energy use. Indeed, the evidence in Figure 9d hints that this is the case. As energy use per worker in US industry increases, so does the share of service-type activity (measured as the employment share of non-production workers).



Fig. 9 Energy use per capita versus service sector employment. This figure plots energy use per capita against service sector employment share. Panel **a** shows the world as a whole. World service employment share is the average of all national data, weighted by national labor force size. Panel **b** shows the trend between countries. Each line represents a country's path through time. Panel **c** shows the distribution of within-country trends between energy use per capita and service employment share. Results are for the scaling exponent α of log–log regressions (see Eqs. 1 and 2). Panel **d** plots two cen-

turies of data from the United States. Panel **e** plots labor structure change *inside* US industry. The growth of energy use per worker in US industry is strongly related to the growth of non-production workers in industry (i.e. service-type workers). R^2 values are for log–log regressions. Grey regions indicate the 95% prediction interval of each regression. All panels (except **c**) use log–log scales. Data for **a**, **b** and **c** come from the World Bank (Table 2), with the exception of world energy use, which comes from the BP Statistical Review 2017. US data sources are discussed in the Appendix





interval of the regression. Panel b shows the distribution of within-

country trends. The 'within-country slope' measures the average

change in service share of value added for a unit change in service

share of employment. All data comes from the World Bank (Table 2)

Fig. 10 Service sector share of value added versus share of employment. Panel **a** plots national data for service value-added share against service employment share. Lines represent the path through time of countries. The R^2 value is for a linear regression conducted on national averages. The shaded region indicates the 95% prediction

Why is there a link between energy use and facilitation activity? A plausible reason is that increasing energy use requires more complex technology (Fix 2017). As an example, consider the difference between subsistence and industrial agriculture. Subsistence farmers produce most of their own tools. Industrial farmers do not. Think of the large machines used by industrial farmers. Now picture the services needed to produce and maintain these machines. This includes the engineers who design the machines, the administrators who coordinate production, the educators who train the skilled workforce, and so on. It may be a general rule that facilitation activity tends to grow as technology becomes more complex. This is consistent with the tendency for social complexity to increase with economic development (Carneiro 1967; Naroll 1956; Zipf 1949).

I have focused on the movement of *employment* between sectors because it makes the flaws in the 'dematerialization through services' hypothesis easiest to spot. But what if a country increases the service sector's share of *value added* without shifting employment? While this may be possible in principle, the evidence suggests it is hard to do in practice. National variation in service sector employment share accounts for about 37% of the variation in service sector value-added share (Fig. 10a). Within countries, a 1% increase in service employment share leads to an average increase of 0.75% in service value-added share (Fig. 10b). This is not hard to understand. Most services are labor intensive (think health care and education) and increasing labor productivity is difficult (Baumol 1967).

Conclusions

In 1972, the Club of Rome released its famous report *The Limits to Growth* (Meadows 1972). Since then, economists have debated whether economic growth can decouple from environmental impact. Proponents of the 'environmental Kuznets curve' argue that decoupling is possible (Grossman and Krueger 1994; Panayotou 1993; Shafik and Bandyopadhyay 1992). The idea is that environmental impact first rises and then falls with economic growth. The transition to services provides a plausible mechanism for this decoupling. Panayotou et al. (2000) propose that "economic growth brings about structural change that shifts the center of gravity of the economy from low-polluting agriculture to high-polluting industry and eventually back to low-polluting services".

The problem with this hypothesis is that it neglects the complex social changes that come with a service transition. As Colin Clark (1940) observed long ago, sectoral change seems to be a key part of economic growth. And economic growth is strongly associated with the growth of fossil fuel energy use (Brown et al. 2011, 2014). When framed this way, it is not surprising that the 'dematerialization through services' hypothesis fails. I find no evidence that a service transition reduces carbon emissions. Instead, it is associated with the *growth* of per capita emissions.

What are the implications for policy makers? It seems that a service transition does not 'automatically' lead to decreased environmental impact. This implies that purposeful policy intervention is required. It is obviously important to decarbonize energy sources by investing in renewable energy. But it is unclear how this relates to sectoral change (if it relates at all). Future research may make this clearer. But for now, we can draw a simple conclusion. The evidence indicates that 'dematerialization through services' is not a valid policy for reducing carbon emissions.

Acknowledgements I would like to thank the anonymous reviewers for comments that have improved this paper. I also thank Charles Hall and Kent Klitgaard for helpful comments on earlier versions of this research.

Compliance with Ethical Standards

Conflicts of Interest The author acknowledges no conflicts of interest.

Appendix

This paper has a supplementary website containing raw and final data as well as code for all analysis: https://osf.io/93fpn/.

A Sources and Methods

US Energy Intensity by Sector (Fig. 1)

Sources and methods for calculating US sectoral energy use, employment, and value added are shown in Table 7. Except for energy consumption in the US service sector, all data is taken as given from the official data. The US Energy Information Agency (EIA) uses energy consumption categories that differ from the standard national income and product accounts categories used by the Bureau of Economic Analysis (BEA). The EIA energy data uses four categories:

 Table 7
 Sources and methods for US sectoral energy use, employment, and value added

	Industry	Services	Source
Energy use	Industry energy	Commercial energy + work-related transport energy	EIA Annual Energy Review Table 2.1 Various Annual Energy Outlooks National Household Travel Survey 2009 and 2017
Employment	Mining	Wholesale trade	BEA Table 6.8D
1 0	Utilities	Retail trade	Persons engaged in production
	Construction	Transportation and warehousing	
	Manufacturing	Information	
	C C	Finance and Insurance	
		Real estate and rental and leasing	
		Professional, scientific, and technical services	
		Management companies	
		Administrative and waste management services	
		Education services	
		Healthcare and social assistance	
		Arts, entertainment, recreation	
		Accommodation and food services	
		Other services	
		Government	
Value added	Mining	Wholesale trade	BEA real value added by industry
	Utilities	Retail trade	
	Construction	Transportation and warehousing	
	Manufacturing	Information	
		Finance, insurance, real estate, rental, leasing	
		Professional and business services	
		Education services, health care, social assistance	
		Arts, entertainment, recreation, accommodation, and food services	
		Other services	
		Government	

EIA Energy Information Agency, BEA US Bureau of Economic Analysis

Years	Sector	Source	Description
1800–1920	All	HSUS Table BA814–830	The labor force, by industry: 1800–1960
1920–1929	Agriculture	HSUS Table BA470–477	Labor force, employment, and unemployment: 1890-1990
1920–1929	Non-agriculture	HSUS Table BA840–848	Employees on non-agricultural payrolls, by industry: 1919–1999
1929–1948	All	BEA Table 6.8A	Persons engaged in production
1948–1987	All	BEA Table 6.8B	Persons engaged in production
1987-2000	All	BEA Table 6.8C	Persons engaged in production
1998–2016	All	BEA Table 6.8D	Persons engaged in production

 Table 8
 Sources for US sectoral labor composition

HSUS Historical Statistics of the United States, BEA Bureau of Economic Analysis

Industrial use, Commercial use, Transport use, and Residential use.

To allocate transport energy to the service sector, I apply the method developed by Giampietro, Mayumi, and Sorman (2012; 2013). I define service sector energy use (E_{Service}) as commercial energy ($E_{\text{Commercial}}$) plus work-related transport energy ($E_{\text{Work-Related Transport}}$).

$$E_{\text{Service}} = E_{\text{Commercial}} + E_{\text{Work-Related Transport}}$$
(4)

work-related transport energy is calculated by subtracting non-work-related energy from transport energy. Non-workrelated transport energy is defined as all transport energy minus light-duty vehicle energy consumed for non-workrelated trips.

$$E_{\text{Work-Related Transport}} = E_{\text{Transport}} - E_{\text{Light-Duty}} \cdot \frac{VMT_{\text{Non-Work}}}{VMT_{\text{Total}}}$$
(5)

Here VMT stands for vehicle-miles-traveled. Data for US light-duty vehicle energy use comes from various EIA Annual Energy Outlooks from 2000 to 2018. Vehicle-miles-traveled data comes from the National Household Travel Survey 2009 and 2017.

US Sectoral Composition and Historical Energy Use (Figs. 7b, d, 8a, 9d)

US sectoral labor composition sources are shown in Table 8. Because the series are not mutually consistent, there is inherent ambiguity in the historical data. To quantify this ambiguity, I use a Monte Carlo technique to randomly splice together the series in different ways. I then use the median of this spliced data.

US historical energy and fossil fuel use data (1800–1945) comes from EIA Annual Review 2009, Table E1. Fossil fuel energy use data begins in 1850. I use an exponential regression to extrapolate trends back to 1800. US energy data from 1949 onward comes from the EIA Annual Energy Review, Table 1.3.

US industry energy use and non-production employment (Fig. 9e)

US industry energy data comes from EIA Annual Energy Review Table 2.1. Industry employment comes from BEA Tables 6.8A-D (persons engaged in production). I calculate employment of non-production workers in industry is using Bureau of Labor Statistics series CES060000006 (Production and non-supervisory employees, goods-producing) and series CES0600000001 (All employees, goods-producing). I define non-production workers as the difference between total employment and production employment.

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