Does product efficiency regulation in Europe lead to an energy efficient world? Examining the global energy use of our used goods exports

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Abstract

It is hypothesised that as a result of used electronic goods exports to developing economies, the projected energy savings made by the Ecodesign Directive at the EU level do not immediately equate to the same savings at the global level. A significant volume of the EU's inefficient used/obsolete products are exported after reaching the end of their useful life in the EU and after a relatively short second usage phase, these products become electronic waste and undergo particularly poor end of life treatment in developing countries. To determine whether the energy use of used exports could be significant, the annual energy use of EU stock and exported used products is simulated in the case of televisions, using a simplified stock model over the time period 2006 to 2025. This simulation is based on available data, estimates and simple projections for the annual number of exported used televisions and annual television energy use over time. The model shows that the scale of energy usage is highly dependent on the number of exported televisions and their second lifetime. Assuming the number of exported used units to average 15 % and be in a range of between 5 % and 25 % of annual EU sales, an indicative estimate of the energy use of exported televisions is found to be 8.1 % (range: 2.7 %–13.6 %) of the annual energy use of EU television stock in 2013. Similarly, the annual energy use of exports is estimated to be 26.9 % (range: 9.0 %–45.0 %) of new EU sales energy use in 2013. Using the model results it can be deduced that Ecodesign regulations first impact the used goods market after the average EU lifetime for the televisions, taken as nine years in this study. Full savings are expected to be achieved at the global level after the second lifetime in the developing world, assumed to be an additional five years in this case (i.e. 14 years total). Further positive effects of Ecodesign regulation at the global level are also discussed, while the model also indicates that the short second lifetimes of used televisions leads to significant WEEE generation in developing countries.

Introduction

As a result of the West's rapid turnover of consumer electronics, increased environmental regulation and cheap global transport, exports of electronic waste from the EU to developing countries have dramatically increased in the past decades, and electronic waste remains one of the EU's fastest growing waste streams (EEA 2012). Electronic waste refers to discarded obsolete electronic devices, including functioning used electrical and electronic equipment (herein: UEEE) and broken/unrepairable waste electrical and electronic equipment destined for end of life treatment (herein: WEEE). Under the European WEEE Directive and Basel Convention it is illegal to export WEEE from the EU due to the hazardous materials contained within, however the export of UEEE remains legal (EU 2012). Many obsolete devices that are still functioning or repairable are therefore exported by third parties to developing countries where they can be sold on for a profit (Williams, Kahhat et al. 2008). For instance, journalists from 'Die Zeit' GPS-tracked an unwanted used cathode ray tube (CRT) television from Hamburg to Ghana in 2014, finding that it sold to a consumer in Ghana several weeks later for 70 Euros (Braun, Pfeil et al. 2014).

Estimating the scale of electronic waste exports is difficult due to a lack of systematic monitoring and reporting at EU level (Breivik, Armitage et al. 2014), however based on German data, the European Environmental Agency estimates that between 500,000 and 1,300,000 tons of electronic waste was exported from the EU in 2008 (EEA 2012).

Considerable research has been carried out in recent years looking at the problems and impacts of WEEE exports to developing countries (Perez-Belis, Bovea et al. 2015). End of life treatment in developing countries does not follow best practice European recycling procedures and often entails either treatment in the informal recycling sector or dumping in unregulated landfill sites, leading to significant toxic emissions, environmental degradation and local health problems (EEA 2012). Less research has been made into the role of reusing UEEE exports in developing countries, and in particular their energy consumption. This is partly due to a lack of reliable export data (Breivik, Armitage et al. 2014), and partly because old goods will eventually be replaced with newer ones at end of life, making analysis lower priority.

When considered together with improvements in efficiency of products placed on the EU market driven by the Ecodesign Directive (EU 2009), it can be expected that UEEE exports have lower efficiency than new products sold in the EU. The additional energy use associated with these globally exported products could potentially offset or delay part of the energy efficiency gains made at the EU level. A survey of the literature shows that no analysis has yet been made on the energy consumption of UEEE exports in the context of energy efficiency regulation. Several studies have considered the broad social, environmental and economic implications of reuse supply chains (Williams, Kahhat et al. 2008; Dwivedy and Mittal 2012), whilst the benefits of reuse for resource efficiency compared with replacement time for buying more efficient products has also been investigated (Truttmann and Rechberger 2006). Other studies have noted the problems of UEEE exports and the donation of old computers to developing countries, specifically that UEEE has a short second lifespan before becoming WEEE (SBC 2011). A detailed study made by Yoshida and Terazono in 2010 gives valuable insights into the reuse of second hand television exports from Japan to the Philippines (Yoshida and Terazono 2010). They estimate an annual export of 2.25 million used television sets in 2008, and by tracking a container full of 814 used television sets were able to establish that 3 % were broken in transport and 40 % had electrical failures on arrival. All of these electrical failures were repaired by the Philippines importer, before the televisions were sold on in local markets. Interviews were carried out with 113 used television buyers in the study; they expected to use the televisions for another five years on average, after which it was expected that the televisions enter the informal and unregulated recycling sector, leading to significant local environmental and health consequences.

RELEVANCE FOR THE ECODESIGN DIRECTIVE

The Ecodesign Directive enables the EU Commission to set minimum energy and resource efficiency standards for new energy using/related products being placed on the EU market (EU 2009). These products range from household appliances and consumer electronics such as refrigerators and televisions, to industrial and commercial products such as motors and fans. Together with the Energy Labelling Directive, which informs and directs consumers to the most efficient products, Ecodesign has proven to be one of the EU's most successful instruments for reducing community energy use and carbon emissions through increasing energy efficiency. Based on the saving potentials calculated in preparatory work for each product group, the overall savings resulting from regulations in force up to November 2013 is expected to equal some 15 % of current EU final energy use by 2030, in comparison to business as usual scenarios (Kemna 2013). Ecodesign regulation is based on evidence provided by market, technical and environmental data, and each regulation is supported by a preparatory study in which a streamlined life cycle analysis (LCA) calculates the impacts that occur in a product's production, distribution, use and end of life phases (Kemna 2011). This is usually followed by an impact assessment, in which a cost benefit analysis for the EU economy is made. Thus far, all current Ecodesign regulations focus primarily on improving energy use in the usage phase of products, as this has been found to have the dominant environmental impact in each product group by Ecodesign LCA. In calculating the energy savings possible in the use phase it is usually assumed that old inefficient devices are mostly substituted by new, more efficient products. Upon reaching the end of their average EU product lifetime, these old devices are assumed to be recycled or landfilled according to the EU recycling rates of their constituent parts (Kemna 2011).

The aim of this study is to examine the relationship between Ecodesign regulation and exported goods by making a first indicative estimate of the energy use of used televisions exported from the EU, and then determining the effects of Ecodesign regulation on the export market over time. Although major additional impacts are expected to occur due to the informal recycling sector, the quantitative focus of this study will be on the *extended use phase* in developing countries, since the use phase dominates in Ecodesign.

Methodology

CASE STUDY: TELEVISIONS

Televisions have been selected for analysis in this study as they have made significant efficiency gains in the last eight years (Michel, Attali et al. 2014), are one of the most investigated products in the context of electronic waste exports (Perez-Belis, Bovea et al. 2015), and relatively good market data is available covering the last 10–15 years. Ecodesign minimum requirements for televisions first came into force in 2010 via directive (EC) No 642/2009 (EC 2009). The minimum requirements for efficiency were based upon the preparatory study findings, however this did not anticipate the rapid transition from cold-cathode fluorescent lamps (CCFL) to light emitting diode (LED) backlighting technology, which has vastly improved the energy efficiency of the television market. As a result, the Ecodesign regulations set had relatively little forcing effect on the market between 2010 and 2014, however the energy label still provided increased efficiency incentives (Michel, Attali et al. 2014). Since 2012 the requirements have been under review, which after some delays, should lead to more ambitious requirements in 2015 (CLASP 2014). Although Ecodesign has as yet had little effect on the TV market, the rapid efficiency gains of televisions present the opportunity to consider the energy use of UEEE exports, as they clearly demonstrate the principle aim of Ecodesign regulation and energy labelling across all product groups.

ENERGY USE STOCK MODEL

To explore the long term effects of exporting used televisions, a simplified stock model is made to show the development of annual television energy use within the EU and of UEEE exports over time. This model helps to demonstrate which dynamics are at play in relation to energy efficiency and used goods markets, enabling us to answer the question of how Ecodesign regulation impacts the efficiency of UEEE exports. The model also gives an indicative estimate of the magnitude of annual energy use resulting from exported used televisions.

Televisions in use within the EU are herein referred to as *EU televisions/stock*, and used television exports which are in use in developing countries are referred to as *exEU televisions/stock*. The model focuses only on annual energy use of EU and exEU stock; transportation and end of life environmental effects are not considered.

EU television stock develops over time according to sales in the EU, which represent the rate of replacement of obsolete televisions (dependent on television lifetime) and additional stock growth of new sales. In line with standard Ecodesign methodology, each new EU television is assumed to be used in the EU (independent of the number of users) until the end of its average EU lifetime, L, before it is discarded. The sales in year y are given by:

$$Sales(y) = ReplacementSales(y) + NewSales(y) \quad (1)$$

where $ReplacementSales(y) = Sales(y - L)$,
i.e. the sales from L years ago.

The installed EU stock in a given year can then be calculated using the average EU lifetime and yearly sales data according to the stock formula:

$$EU\ Stock(y) = \sum_{t=y-L}^{t=y} Sales(t) \quad (2)$$

Instead of assuming all discarded televisions enter EU recycling/landfill waste streams at the end of their lifetime as in Ecodesign, it is assumed that a significant fraction of used televisions are exported to developing country markets where they continue to use energy as exEU stock. The proportion of televisions exported is denoted by the export factor, e. Of the televisions exported, a fraction can be expected to be broken and unrepairable WEEE; the functioning fraction of the exports is therefore denoted by the factor f. The lifetime of the used televisions after export is denoted by the second lifetime, l, and expected to be shorter than the EU lifetime. The exEU stock is then calculated according to the following:

$$exEU\ Stock(y) = \sum_{t=y-l}^{t=y} ef \cdot Sales(t) \quad (3)$$

These used televisions are assumed to use the same annual energy as they did in the EU over their second lifetime, l, before entering waste streams in the developing country as WEEE. The number of used EU televisions entering developing country WEEE flows is taken as the sum of yearly non-functioning exports plus the sum of exEU televisions reaching the end of their second lifetime in the developing country. This is given by the following formula, where $t = 0$ represents the baseline year used for the analysis:

$$exEU\ WEEE\ Stock(y) = \sum_{t=0}^{t=y} e(1-f) \cdot Sales(t) + \sum_{t=0}^{t=y-l} Ef \cdot Sales(t) \quad (4)$$

A comparison of the annual energy use of the EU and exEU stock can be made using average on-mode and standby power data for each year. Annual energy use of EU televisions in kWh for a given year is calculated according to:

$$Annual\ Energy\ Use = EU\ Stock(y) \times 365 \cdot \left(\frac{P_{on}(y)t_{on} + P_{standby}(y)t_{standby}}{1000}\right) \quad (5)$$

$P_{on}(y)$ = Average on mode power (W) in year y
$P_{standby}(y)$ = Average standby power (W) in year y
t_{on} = daily time in on-mode (hours)
$t_{standby}$ = daily time in standby (hours)

EU STOCK DATA

Sales data, average EU lifetime and average television power data are required to simulate the EU stock. Table 1 shows the data which has been used to generate the model. Gaps in the data have been filled by extrapolation and basic projections are made until 2025 to illustrate longer term effects; data values marked with a * represent extrapolations or projections.

Sales Data

EU television sales data is given from 1998 to 2004 in the preparatory study for Ecodesign (Fraunhofer 2007), whilst Topten's market review in 2014 gives sales from 2007 to 2013 (Michel, Attali et al. 2014). For the missing years of 1997, 2005 and 2006, the sales data values are extrapolated. After 2014 it is projected that new sales of televisions stay constant at 40 million a year through to 2025.

On-mode and Standby Power Data

For television on-mode power the average power of all television sizes placed on the market is used. Annual energy use is calculated in line with Ecodesign, assuming 4 hours a day in on mode and 20 hours a day in standby for all televisions (Fraunhofer 2007). Average on-mode power values are given in Topten's market review from 2007 to 2013 (Michel, Attali et al. 2014). However it is difficult to find data prior to 2007, only an average value of 122 W in 2005 could be derived from the Ecodesign preparatory study for televisions (Fraunhofer 2007). In the years before this it is assumed that CRT television on-mode power averages 110 W, as these had lower power consumption than LCD models until 2010 and dominated the market until 2004/2005. By 2008 however, CRT Televisions

Table 1. EU data inputs for the stock model.

Year	EU Sales	Average On-mode Power (P_{on})	Average Standby Power ($P_{standby}$)
1997	27.0*	110*	4.5*
1998	27.4	110*	4.5*
1999	28.5	110*	4.5*
2000	30.3	110*	4.3
2001	29.9	110*	4.0
2002	30.3	110*	3.6
2003	30,7	110*	2.5
2004	31.1	115*	2.4
2005	34.3*	122	2.3
2006	37.6*	134*	2.2
2007	41,0	145	2.1
2008	46.0	156	2.0
2009	52.0	140	1.5
2010	56.0	118	1.0
2011	54.0	96	1.0
2012	47.0	70	1.0
2013	41.0	55	1.0
2014	40.0*	50*	1.0*
2015	40.0*	45*	1.0*
2016–2025	40.0*	40*	1.0*

represented just 11 % of new sales, dropping to 3 % the year after (Michel, Attali et al. 2014). It is assumed that current efficiency improvements bottom out at an average on mode power of 40 Watts in 2016 and stay constant until 2025. This projection is reasonable as a trend towards smart and larger TVs will likely offset some efficiency increases (CLASP 2014).

EU Television standby power data are available from the IEA 4E standby initiative from 2000 to 2009 (IEA 2012). From 1997–1999 an average standby power of 4.5 W is assumed, whilst beyond 2009 it is assumed that standby power remains in limits of the Ecodesign standby regulation at 1 W. This ignores the fact that many network enabled (smart) televisions now have higher network standby power allowances of up to 6 W (EU 2013).

EU Lifetime and EU Stock

According to the literature, televisions have lifetimes ranging from 7–15 years, however this has reduced over time as technological progress has caused replacement rates to increase (Fraunhofer 2007). Fakhredin & Huisman estimate the EU lifetime of LCD televisions to drop from 9.7 years in 2006 to 9.0 years in 2012 (Fakhredin and Huisman 2013). This is in agreement with analysis by Yoshida and Terazono, who found that the majority of used televisions exported from Japan to the Philippines were 8–10 years old (Yoshida and Terazono 2010). To calculate the EU stock, a value of 9.0 years is therefore taken in this analysis. Summing the annual sales of televisions sold in each year of this lifetime according to Table 1 gives an EU stock estimate in 2013 of 408.9 million units, which compares favourably with the stock estimate made by the Ecodesign preparatory study of 391.5 million for 2010 (Fraunhofer 2007).

The projection of 40 million annual sales from 2014 to 2025 leads to a stock saturation of 360 million units in 2022, or 1.76 televisions per household based on 205 million EU households in 2010 (Kemna 2011). This projection is plausible, however replacement sales may increase due to another technical switchover to e.g. 4K definition.

EXPORT DATA

Export Fraction

Across both Europe and developing countries there is a lack of reliable data on the export and import of UEEE due to imperfect monitoring and sales alongside new goods (Breivik, Armitage et al. 2014). Whilst the number of exported used televisions from the EU is uncertain, it seems likely that the order of magnitude is in the millions. A study by Sander & Schilling in 2010 for the German Environment Agency (UBA) made detailed analysis of used goods flows through the port of Hamburg (Sander and Schilling 2010). They found that major discrepancies and uncertainties occur between export data and import data between countries, largely because of limited declaration requirements for low value goods. The authors compare German export declarations with television import declarations in the main export destinations of Ghana, Nigeria, South Africa, India, Vietnam and the Philippines. Import figures were often found to be much higher than export declarations, with Ghana and Nigeria respectively registering 3,391 tonnes and 349,738 tonnes of televisions/monitors imported from Germany in 2006. It is similarly difficult to place high confidence on other import declarations, UN Comtrade databases show for instance imports of 627,000 new and used television units to Ghana in 2008 (Amoyaw-Osei, Agyekum et al. 2011). By comparing various sources, Sander and Schilling estimate that 50,000 tonnes (weighted average, range: 28,000 to 76,000 tonnes) of used CRT monitors were exported from Germany to the above-listed countries in 2008, equating to some 2 million units (Sander and Schilling 2010). At the single country level, this magnitude of exports is supported by the estimate that 2.25 million used televisions were exported from Japan in 2008 (Yoshida and Terazono 2010).

Another approach is made by a study looking at WEEE flows in the Netherlands. This estimates the generation of WEEE in 2010 per inhabitant using an accurate UNU WEEE generation model, cross-checking with various data sources (Huisman, Maesen et al. 2012). In 2010, 1.74 kg of TVs was placed on the market per inhabitant and an estimated 1.84 kg of W/UEEE was generated – of higher weight due to the switch from heavier CRTs to LCDs. Of the generated W/UEEE, 0.49 kg per inhabitant was exported, representing 28 % of the weight of televisions put on the Dutch market in 2010.

In order to compare the energy use of exported products in the context of EU Ecodesign, it is necessary to consider all exports of used televisions from the EU. It is reasonable to assume that the number of television exports is dependent on the number of new televisions placed on the EU market, as replacement sales lead to W/UEEE generation. The Dutch study therefore gives a more dynamic yearly input for the stock model, as it is possible to state UEEE exports as a fraction of annual new sales in the EU. The percentage which should be taken is however subject to high uncertainty. Firstly, as technology has changed from CRT to LCD, the average weight of televisions has decreased. However we now also see trends towards heavier,

Table 2. Input parameters for stock calculations.

EU TV lifetime (L)	9.0 years
Used TV lifetime after export (l)	5.0 years
Fraction of functioning TVs on import (f)	85 %
Percent of annual exports as fraction of new sales (e)	15 % (Range: 5 %–25 %)
Daily time in on-mode (t_{on})	4 hours
Daily time in standby ($t_{standby}$)	20 hours

larger televisions (Michel, Attali et al. 2014), while the smaller dimensions of LCD televisions may make export more profitable as transport costs per unit come down. Secondly, it must be asked if the Dutch population can be taken as representative of the EU, as the turnover of televisions may be different in Holland when compared with new Eastern European member states, where incomes are lower. It is therefore proposed to take an exports estimate equating to 15 % of sales, adapting the factor of 28 % based on EU-15 vs. EU-24 population[1] (multiply by 0.80) and assuming the average weight of televisions being placed on the market to be one third lighter than the W/UEEE being generated in 2010 (multiply by 0.67). Since this number is crucial to the analysis, it is proposed to take 15 % as an average and give results based on the range of 5 % to 25 % (range: 5 %–25 %) export rates.

Working from these assumptions, the number of used televisions exported from the EU in 2013 is estimated to be 6.2 million units (range: 1.7–8.7 million), given that 41 million televisions were sold in the EU in 2013 (Michel, Attali et al. 2014). Given that it is possible to fit 900 CRT televisions (and even more flatscreens) in one shipping container (Sander and Schilling 2010), it would require the export of 18.9 containers from the EU each day to reach this annual value. For comparison, it has been estimated that exported used and scrap personal computers represent 6–29 % of end use flows in 2010 in the United States, representing 2–12 million (average 7 million) exported units (Kahhat and Williams 2012).

Functioning Fraction

A relevant fraction of the used televisions exports are likely to be illegal exports of E-Waste. Amoyaw-Osei et al. estimate that 15 % of used goods arriving in Ghana are broken beyond repair on arrival, thereby constituting WEEE (Amoyaw-Osei, Agyekum et al. 2011). Another analysis made on 45,000 W/UEEE personal computers exported from the United States to Peru in 2009 showed that over 85 % entered reuse (Kahhat and Williams 2012). In the stock model it is therefore assumed that 85 % of the exported televisions are functioning and/or repairable.

The informal repair sector in developing countries tends to be very effective, able to repair broken devices on arrival and significantly extend the useful lifetime of obsolete goods. In Ghana, for instance, at end of life some 57 % of goods are first taken to repair facilities instead of informal recycling/landfill (Amoyaw-Osei, Agyekum et al. 2011). Since the exported televisions are towards the end of their useful functional life, it is proposed to take a value of 5 years for the extended lifespan of the product, in line with expectations of 113 used television buyers interviewed in the Philippines (Yoshida and Terazono 2010). The functional unit for the usage of the used television is taken to be the same as in Ecodesign at 4 hours/day in on-mode and 20 hours a day in standby (Fraunhofer 2007).

The additional parameters used to calculate stock data are shown in Table 2.

CRITICAL ASSUMPTIONS

Aside from estimated data points, the model makes the following assumptions:

- No changes occur to future export flows.
- A consumer market always exists for however many televisions are exported from the EU.
- Televisions will be operated for 4 hours a day, 20 hours standby during their second lifetime.
- Televisions of all sizes are exported and used.
- Lifetimes of televisions in use do not change over time.

Model Results

TELEVISION STOCK INSIDE AND OUTSIDE THE EU

Figure 1 shows the stock of televisions in the EU over time, the stock of exEU televisions being used outside the EU, and their eventual contribution to WEEE in the developing world. The graph starts from 2006, as nine years of sales are first available from 1997 to 2005; for used television exports and the resulting WEEE, a baseline of zero is taken in 2006 to clearly demonstrate stock development.

The EU stock first increases from 2006 to 2015, primarily due to the increased sales of the CRT- LCD technology shift, which reached its sales peak of 56 million in 2010. After 2015, the EU stock of televisions reduces again, levelling off at 360 million units in 2022. For comparison, an estimate of 350.45 million television units in stock has been found for 2003 (Nationmaster 2003). This is higher than the 2006–2009 model estimates and can be attributed to the fact that televisions had a longer lifetime before the technological/digital switchover. It is also possible that the nine year lifetime underestimates the number of obsolete televisions which become secondary or tertiary televisions in the household. Over the first five years,

1. EU-24 population is taken as 499.3 million according to market coverage of EU-24 for television sales by Topten study. Eurostat data gives EU population of EU-15 as 397.4 million in 2010.

the exEU stock increases in line with yearly exports, as it is assumed that all exported used televisions have a five year lifetime. Thereafter the used television stock growth plateaus at around 32 million units in 2011, as the 2006 exports reach the end of their second life and become WEEE. At this point new imports represent replacement of broken units and exEU stock increases or decreases according to sales in the EU. For comparison, in 2011 the penetration rate of televisions in Nigeria (Africa's main UEEE trading hub) was estimated at 0.25 per capita (SBC 2011), equivalent to 41 million televisions. From 2006 to 2010 the exported WEEE rises slowly, in line with the assumed unrepairable 15 % of annual used TV exports, before in 2011 the first used exports reach the end of their second life and WEEE increases more rapidly thereafter.

The level of EU-WEEE in developing countries would have already been significant in 2006. Figure 1 clearly shows the problem of allowing export of functioning goods, since these used goods also quickly become WEEE in developing countries. If this trend continues, the sum of WEEE televisions in developing countries will eventually exceed the number of televisions in use in the EU. In the sensitivity analysis section below it is seen that the rate of growth of exEU and WEEE stock is highly dependent on the export percentage taken, for instance, an upper bound export percentage of 25 % leads to far greater WEEE accumulation of 239.5 million units in 2025.

ANNUAL ENERGY USE OF EU SALES VS. USED EXPORTS

Figure 2 shows the development of the total annual energy use for yearly EU sales and yearly used television exports. The annual energy use from 1997 to 2004 is to be viewed with caution, as it is based on on-mode power estimates as noted in the methodology. The relatively constant annual energy use over this time period results from gradual increases in sales offsetting minor improvements in standby power. From 2005 to 2010 the technology switchover from CRT to LCD can clearly be seen as the energy use of yearly EU sales rises, peaking at 11.2 TWh in 2009. This is due to the fact that the first LCD televisions consumed 80 % more energy than the CRT televisions they were replacing (Michel, Attali et al. 2014), whilst the technology switchover pushed higher sales numbers. In 2005 CRT televisions still represented around 70 % of the market, however by 2007 this share had dropped to 24 %. By 2010 the LCD efficiency had improved beyond that of CRTs, however this coincided with the switchover to digital broadcasting and more affordable LCDs, whereby EU sales peaked at 56 million units (Michel, Attali et al. 2014). Together with rapid efficiency improvements and lower sales volumes, the total annual energy use of new sales drops rapidly to 3.6 TWh in 2013. In the simplified future projection, it is seen that EU sales annual energy use is constant until 2025, in line with the assumptions that on mode power levels off at 40 W and sales stay constant at 40 million a year.

Starting from 2006 at the end of nine years EU lifetime, the used exports energy use increases less prominently, as it is based upon the energy use of nine year old CRT units which are assumed to have reached a high level of efficiency (110 W) by the late 90s. The first peak observed in 2010 occurs due to the increase in new EU sales which cause more obsolete units to be exported (according to the model assumptions). The second peak is seen in 2017 as the most inefficient LCD televisions from 2008 are exported nine years later. It can be seen that from 2006 to 2021 the energy use of exported used televisions

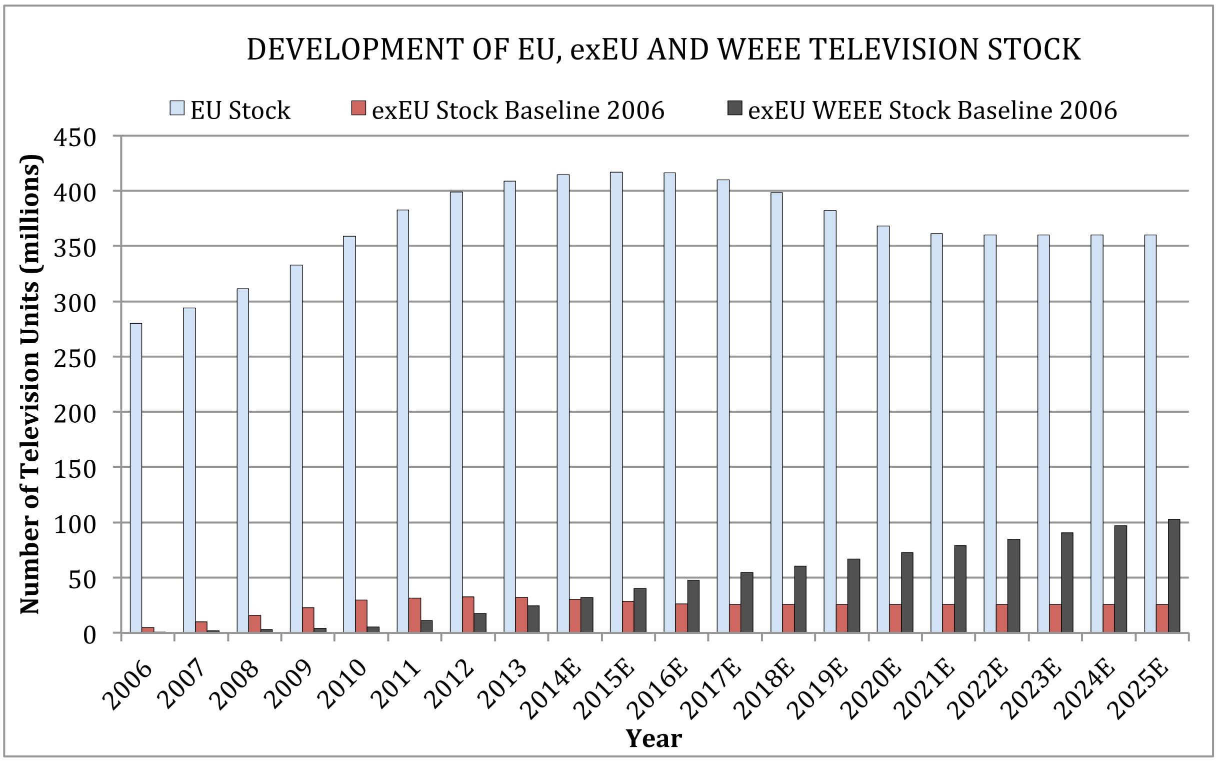

Figure 1. The stock of televisions in use in the EU, the exEU stock in use outside the EU, and the WEEE resulting from used EU television exports. Exports and WEEE start from the baseline 0 in 2006; years followed by 'E' indicate calculations based on future assumptions.

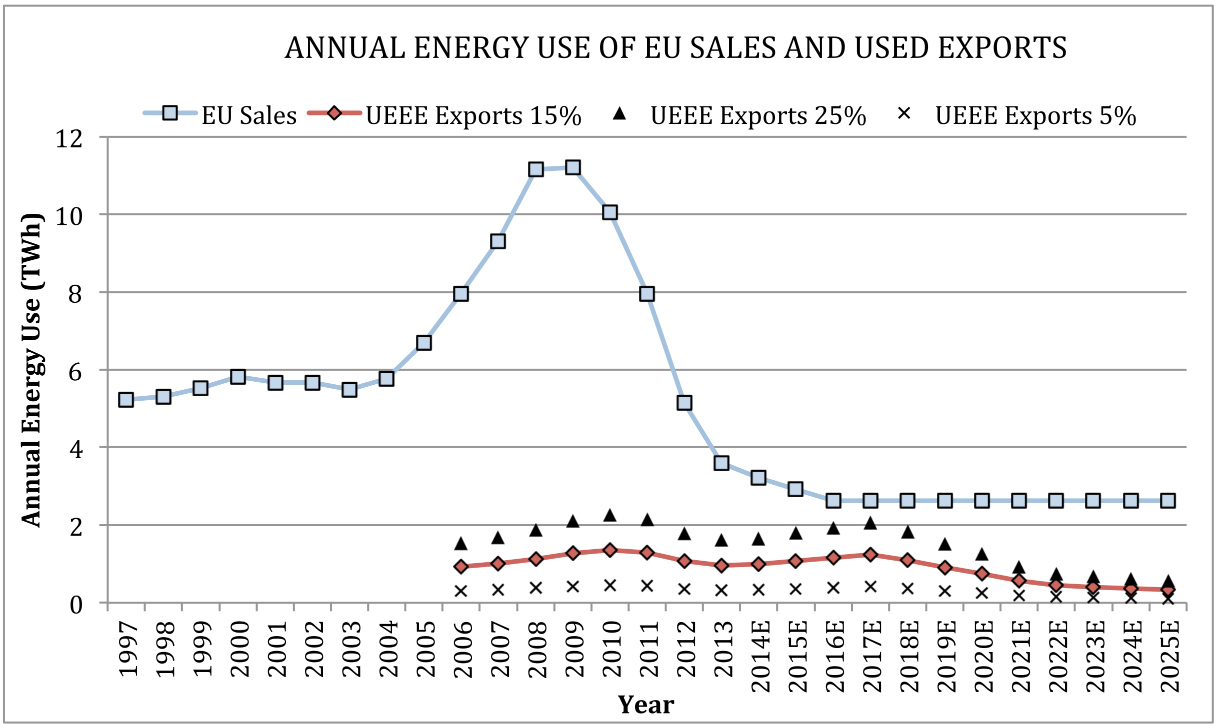

Figure 2. Total annual energy use of EU sales and exported units per year; years followed by 'E' indicate calculations based on future assumptions. Data points for the range 5 % to 25 % are plotted to show the sensitivity of export value taken.

represents a significant fraction of the energy use of EU sales. In 2013, the energy use of the used televisions is 0.97 TWh, equivalent to 26.9 % of the energy use of new televisions placed on the market (Range: 0.32 TWh to 1.62 TWh or 9.0 % to 45.0 %). This percentage is not a rebound effect, as it represents additional global energy use of televisions. It shows that on a *year for year basis*, direct efficiency savings made in EU sales can be partially offset at the global level by used exports. Figure 2 demonstrates that the full savings of energy efficiency improvements on EU televisions are first seen at the global level nine years after the efficiency improvements occur on the EU market, and come to full fruition at the end of the television's second life, i.e. after 14 years.

TOTAL ANNUAL ENERGY USE OF EU STOCK AND EXEU STOCK

Figure 3 shows the total annual energy use of all televisions in terms of EU stock and exEU stock. As the stock and efficiency of televisions increases and decreases over time, so too does the total annual energy use. After peaking in 2011–2012 the energy use of the EU stock decreases as less efficient televisions are replaced with more efficient televisions. The energy use of the exEU televisions represents a small but significant additional annual energy use (8.2 % in 2013; range 2.7 %–13.6 %); however the size of this stock energy use is limited by the five year second lifetime. The export stock reaches a peak additional energy use as a proportion of EU stock (18.4 %; range 6.1 %–30.7 %) in 2020, 12 years after the peak in average on-mode power at 156 W in 2008. This represents the year when the most inefficient televisions from 2006–2010 are all in use outside the EU, whilst the energy use of televisions in the EU has reached a low value. In the years after this, the efficiency improvements also impact the used goods market.

SENSITIVITY ANALYSIS

Sensitivity analysis is carried out for the export percentage as this has the highest impact on results. Other important variables whose variability is not taken into account here are the functioning fraction, the EU lifetime, and the second lifetime. Increased lifetimes would lead to increased stocks, and thereby higher additional global energy use and/or increased EU stock energy use.

Sensitivity analysis over the range of 5 % and 25 % exports as a percentage of EU sales in Table 3 shows how important the number of exports is to the calculation results. The effect of lower or higher export rates is substantial. It can be seen that lower export rates of 5 % of EU sales give additional energy usage which is of low significance as a percentage of the overall EU stock energy use, at 2.7 % in 2013 and 6.1 % in 2020. However, if export rates are towards the higher end of 25 %, the energy usage becomes significant related to the EU stock, representing 13.6 % in 2013 and 30.7 % in 2020, before dropping again to 14.9 % by 2025. The impacts are also very much larger on WEEE accumulation, giving deposition from 8.1 to 40.5 million units in 2010, and from 24.2 to 121.2 million units in 2020. Again it can be seen that lower export rates would pose less of a problem to developing countries.

Discussion

MAIN FINDINGS

The model is based on a number of strong assumptions; however it provides some interesting insights into the energy usage of used goods exports, allowing us to infer the impacts of the Ecodesign Directive on used goods flows and give a first indicative estimate of the energy use of used television exports. From

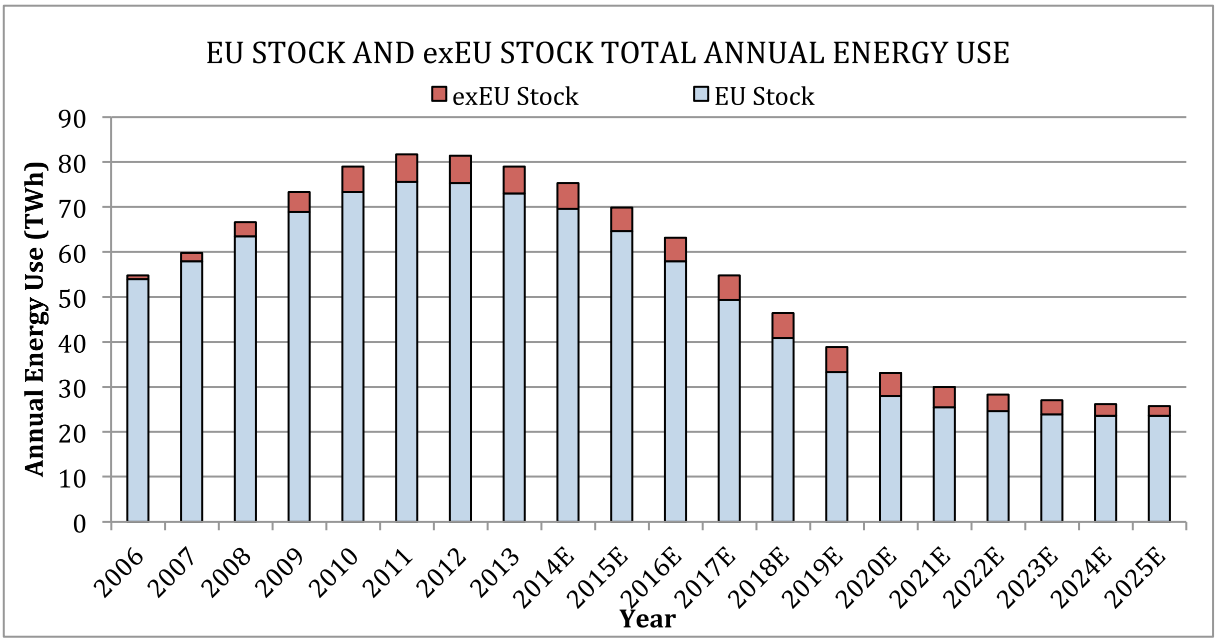

Figure 3. Annual energy use of all EU Television and ex-EU television stock; years followed by 'E' indicate calculations based on future assumptions.

Table 3. Sensitivity analysis based on export rates of 5 %, 15 % and 25 % of EU sales.

Year	2013			2020 (projected)		
EU Sales (Millions)	41			40		
Export Percentage	**5 %**	**15 %**	**25 %**	**5 %**	**15 %**	**25 %**
No. Functioning Exports (Millions)	1.7	5.2	8.7	1.7	5.1	8.5
ExEU Stock (Millions)	10.6	31.9	53.1	8.5	25.5	42.5
exEU WEEE Stock (Millions)	8.1	24.3	40.5	24.2	72.7	121.2
Energy Use of EU Stock (TWh)	73.1	73.1	73.1	28.0	28.0	28.0
Energy Use of Exports (TWh)	0.32	1.0	1.6	0.25	0.75	1.3
Energy Use Export Stock (TWh)	2.0	6.0	9.9	1.7	5.2	8.6
% of EU Stock Energy Use	2.7	8.2	13.6	6.1	18.4	30.7

the sensitivity analysis, it is clear that the number of exports has a very significant effect on both expected energy use of exported goods and the rate at which WEEE accumulates in the developing world. The difficulty of determining a reliable value for the number of past and future exports means that the model results are to be treated with uncertainty. In addition, the lifetime taken for EU and exEU televisions is of high importance in determining the stock values. Comparison with empirical data suggest that the lifetime estimates of nine and five years may be a little conservative.

The analysis allows the following conclusions to be drawn:

1. *There can be a significant additional energy usage associated with UEEE exports.* UEEE exports from the EU that are re-used in the developing world have an associated energy use. For as long as there continue to be UEEE exports, this additional energy use will continue to be present. The limited extended lifetime expected for UEEE limits the additional total annual energy use caused.
2. *Energy efficiency improvements due to regulation or technical innovation are first observed in the used goods export market at the end of the average EU product lifetime. The full global savings are first seen at the end of the used product's second lifetime.* Over time, efficiency improvements also slowly reach the used goods market and as used exports stop functioning, they too are replaced by more efficient used exports. Ecodesign regulations will therefore first take effect on the used goods market after the average EU product lifetime, and have their full impact at the end of the second lifetime. While Ecodesign may therefore have immediate energy efficiency impacts in the EU on entry into force, a small part of the savings made at the EU level will be offset on the global level by the export and continued use of UEEE. The

full direct impact of Ecodesign regulation at the global level is therefore delayed. Nevertheless, when successfully implemented, the Directive should still achieve its primary goal of reducing EU energy use. As the Ecodesign Directive is a market entry instrument, it can only effectively address new products being sold on the EU market. In this regard, the assumption that regulation effects eventually trickle down to used goods markets appears to be correct.

3. *UEEE exports significantly contribute to accumulation of WEEE in developing countries.* Depending on the number of UEEE exported, the accumulation of WEEE in developing countries as a result of short second lifetimes can be substantial. In the stock model, the amount of WEEE resulting from eight years of television exports from the baseline of 0 in 2006 is estimated at 24.3 million units (range 8.1–40.5 million) in 2013. Based on the assumptions made up to 2025, the model predicts accumulation of 143.1 million units of WEEE (range 47.1–238.5 million). Unless WEEE treatment in the developing world dramatically improves, this can be expected to have significant environmental, social and health impacts. The rapid rate of WEEE generation also poses the question of whether the short-lived reuse of products in the developing world is always beneficial, as the impacts of the informal recycling sector could outweigh the resource savings made through reuse.

DYNAMICS OF UEEE EXPORTS

In developing the stock model, it is seen that a large number of dynamics are at play. These range from the changing technological aspects in the EU such as increasing screen sizes, reduced weight and improved efficiency, to various macroeconomic factors including currency exchange rates, transport costs, demand for used goods and legislation.

In the analysis it was assumed that exports can be taken as directly proportional to the number of EU sales each year and extrapolated based on Dutch data. This is necessary to demonstrate the impact of energy efficiency regulation over time, however it requires that there is always a consumer market for the used televisions. Given that used products have short second lifetimes, the argument can be made that the replacement market for used goods remains active enough to ensure that there is always enough demand for future used goods exports. However it might also be argued that the demand for used televisions will reduce in the future. Developing countries are increasingly aware of the problem of inefficient imports; for instance, Ghana has implemented import bans on inefficient second hand refrigerators, freezers and air conditioning units (Dramani and Tewari 2013). According to internet sources, this has allegedly led to reductions in imports of second hand refrigerators by 63 % (UNDP 2013). At the same time, lower prices of new televisions produced in Asia may mean newer technologies become more relevant for consumers than used imports (Michel, Attali et al. 2014).

In the Japanese export study by Yoshida and Terazono, it was found that the profitability of used television exports to the Philippines was highly dependent on the currency exchange rate, with one interviewed importer halting used television exports to the Philippines between 2003 and 2004 as the Japanese Yen lost strength against the Philippine Peso (Yoshida and Terazono 2010). However, while exports to specific countries (e.g. Hong Kong, China) vary significantly in the estimates for Japanese exports, the total volume remains consistent between 2004 and 2008, rising gradually from 2.1 to 2.25 million units. It is therefore likely that the global trade in used exports will continue until the sales price and local availability of equivalent new televisions reaches parity with the costs of transporting, repairing and reselling used television exports.

UEEE gives consumers in the developing world access to technology and services that would otherwise have been unaffordable. However, in general UEEE also have higher energy usage which may mean high operating costs for consumers and present a burden to the energy supply infrastructure of developing countries, which often already struggles to generate enough power to meet energy demand. The short second lifetime of used goods also means that poor consumers must purchase a subsequent television when their first used television breaks beyond repair, becoming WEEE. To avoid this situation, a solution could be to ban imports of all used electronic goods in favour of new purchases. However this would only be effective if it was ensured that new products sold at a similar price level have not only higher efficiency performance, but also have a longer lifetime than the used products being imported. This would not necessarily be the case for cheaply manufactured goods in the same price range. Any import ban would therefore ideally be supported by an Ecodesign-style minimum efficiency and lifetime standard. As with the Ecodesign and WEEE directives, these standards and an import ban would also require effective enforcement.

Although part of the global savings from Ecodesign are delayed by used television exports, it can be expected that Ecodesign has further indirect positive effects on new televisions produced at the global level. As a result of Ecodesign, many of the larger Asian manufacturers will mass-produce more efficient goods for the European market, while at the same time international alignment of energy efficiency test procedures and regulations also has the potential to influence efficiency regulations in producer's home markets, such as China or Korea (CLASP 2014). Consequently, it can be expected that efficiency innovations and improvements will also reach new goods markets where the absence of efficiency regulation would otherwise enable manufacturers to export televisions which are less efficient than the televisions sold to the EU market. Furthermore, for developing nations seeking to implement energy efficiency policies of their own, Ecodesign presents well-defined regulation requirements which can be followed.

Further Investigation

This study has presented a simple first analysis of the energy use that results from used television exports, and how it relates to Ecodesign regulation. The analysis is limited by the current quality of export data. Further analysis carried out based on improved data would improve the reliability of the estimates made here. It is likely that these issues do not apply to all Ecodesign regulated products and it would be interesting to determine whether such impacts are relevant for other consumer electronics, white goods, and air conditioning. Further investigation is required into the environmental and health impacts of used goods once they reach the informal recycling sector, along with possible increased emissions from more intensive energy infrastructure. It could be asked if this is on a scale which becomes relevant for the end of life LCA in Ecodesign preparatory studies.

Important questions remain relating to what extent the used goods from the EU represent additional energy use as compared to a business as usual approach in the importer country. In 2011 the used equipment purchase rates in Ghana and Nigeria were estimated to be in the range of 70 % and 35–70 % respectively (SBC 2011). If an import ban of used televisions blocks poorer consumers from access to the market, is this ethically acceptable? What happens when import bans are successfully implemented? Would consumers buy new televisions with higher efficiency and longer lifetime instead? Or would the consumers simply go without? Is the import of used goods from Europe better than the import from other regions? Does the short lifespan of UEEE before becoming WEEE make reuse of second hand imports worse than purchasing new products in developing countries? Do countries without efficiency regulation suffer from imports of new products with low efficiency and poor quality?

Conclusions

The annual energy use of used televisions exported from the EU has been estimated from 2006–2025 based upon a highly simplified stock model. There is large uncertainty due to unreliable export data and some strong assumptions, so the estimates should only be viewed as indicative; however they do find that the energy use of used televisions outside the EU can be significant.

- The number of annual exports is assumed to be 15 % of EU television sales each year; results are given over the range 5 %–25 %. In 2013, this assumes exports of 6.2 million (range: 1.7–8.7 million) used televisions with an average on mode power of 122 W, compared to 41 million new EU sales with on mode power averaging 55 W. Assuming the same usage conditions outside the EU, the annual energy use of used television exports in 2013 represents 26.9 % (range: 9.0 %–45.0 %) of the annual energy use of new EU sales in the same year. In terms of total stock, the energy use of used export stock in continued use with a five year lifetime is estimated to be 8.1 % (range: 2.7 %–13.6 %) of the total energy use of EU stock in 2013. The limited lifetime of used television exports outside the EU limits their total additional energy use.

- The model demonstrates the effect of energy efficiency changes on the used export market over time. A successful Ecodesign regulation should achieve its EU saving potentials, however it is deduced from the model that Ecodesign regulation would first impact the used exports market after the average EU lifetime of the product, taken to be nine years for televisions in this study. The full global savings are not seen until used exported televisions reach the end of their second lifetime in the developing world, taken to be an additional five years.

- A large number of dynamic variables affect used goods exports and new goods sales. It is likely that Ecodesign regulation has a number of indirect positive effects on new mass-produced goods exported to unregulated markets, and also on the ambition and quality of efficiency standards set in other countries.

- The stock model shows that the short lifespan of used goods leads to high levels of WEEE generation in developing countries. Depending on export rates, this can be substantial: starting from a baseline of 0 in 2006, the resulting developing country WEEE from EU exports is estimated to be 24.3 million units (range: 8.1–40.5 million) in 2013.

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