CO_2 emissions from the residential sectors in Europe: drivers and distributive consequences (Preliminary draft)

Dorothée Charlier[a], Mouez Fodha[b]*, Djamel Kirat[c]

(a) University of Montpellier and ART-Dev. Site Richter, Rue Raymond Dugrand, CS 79606, 34960 Montpellier, France.

(b) Paris School of Economics and University Paris 1. 106-112 Bd de l'Hôpital, 75647 Paris, France.

(c) University of Orleans, LEO, Faculté Droit-Economie-Gestion, Rue de Blois, 47000 Orléans, France.

April 5, 2016

Abstract

This paper investigates empirically the causal factors of the CO_2 emissions from the residential sectors for 14 European countries during the $1990 - 2012$ period. We find significant effects of both economic and climatic variables on CO_2 emissions. We compute the distributional impacts of a European carbon tax ($20e/ton$) and show that it increases the inequalities among countries, in terms of tax revenue-to-GDP ratio. We finally simulate the country-specific carbon tax policies that equalize the burden among countries. We define the compensatory transfers that may correct these inequalities, increasing therefore the acceptability of the environmental policy. Basically, these transfers represent (in average) 5% of the cost of the European Union climate and energy package.

Keywords: CO2 emissions, distributional effects, geographical heterogeneity, residential sector, panel data.

JEL classification: E62 - H23 - Q48.

1 Introduction

Can we consider the carbon tax as an efficient complement to the EU ETS for the still unregulated emissions, like the CO_2 emissions from the residential[1] sectors? In 2014, five European countries (out of 28 members)

*Corresponding author, mouez.fodha@gmail.com.

[1] CO_2 emissions from the residential sectors represent more than 20% of total emissions in Europe.

Table 1: Carbon taxation in Europe in 2014

Country	Amount of carbon tax 2013-2014 (€ per tCO2)	Establishing
Finland	30	1990
Norway	4-69	1991
Sweden	160	1991
Denmark	31	1992
Ireland	20	2010
UK	15	2013
France	7	2014

impose a carbon tax, without any coordination at the European level (see Table 1). In 2011,[2] the E.C. proposed the "Introduction of an additional uniform CO2-related tax: this tax would be added to the taxes already levied under the Taxation Directive Energy and complement the E.U. emission trading system".[3] This CO_2 tax would be set at €20 per ton. More recently, the OECD (2013) suggested that carbon taxes and emission trading systems are the most cost-effective means of reducing CO_2 emissions, and should be at the center of government efforts to tackle climate change.

The objective of this paper is to measure the consequences of the geographical and economic heterogeneities on the burden of the carbon tax. We use a panel data of 14 European countries over the period 1990-2012. The study of the geographical characteristics highlights heterogeneities among these countries. For instance (see Figure 1), there is up to 4000 Heating Degree Days[4] gap between European countries. There are also significant differences in terms of energy consumption and CO_2 emissions.

The development level and wealth of European countries are also different (see Figure 2); some countries such as Poland, Hungary and the Czech Republic have GDP per capita below 10 000 € yearly, which is less than a quarter of the GDP per capita of the richest countries like Norway and Denmark. Finally, the energy characteristics are also country specifics, i.e. energy prices and energy mixes (gas, electricity, coal and oil) are very different from one European country to another. The Scandinavian countries use mainly

[2] A uniform carbon taxation in Europe was suggested in the 90's, first in the White Paper on "Growth, competitiveness and employment" (1993) and then in Dreze and Malinvaud (1994). It gave birth to huge debates mainly on the macroeconomic consequences of ecotaxation.

[3] Impact Assessment Accompanying document to the Proposal for a Council Directive amending Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity - COM(2011) 169 final - SEC(2011) 410 final, Commission Staff Working Paper, European Commission, 2011.

[4] It reveals the significant differences between European countries in terms of heating needs.

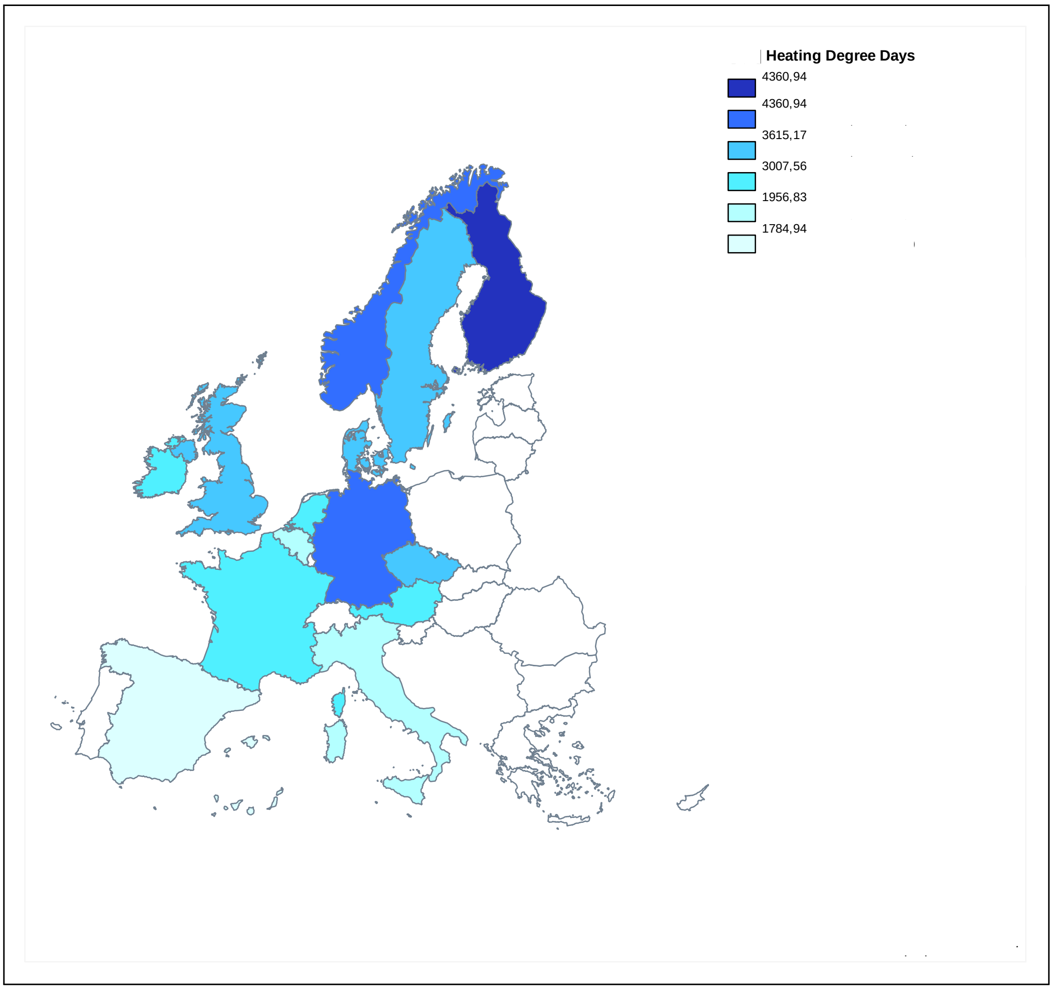

Figure 1: Emissions per capita in 2012 and average GDP growth rate

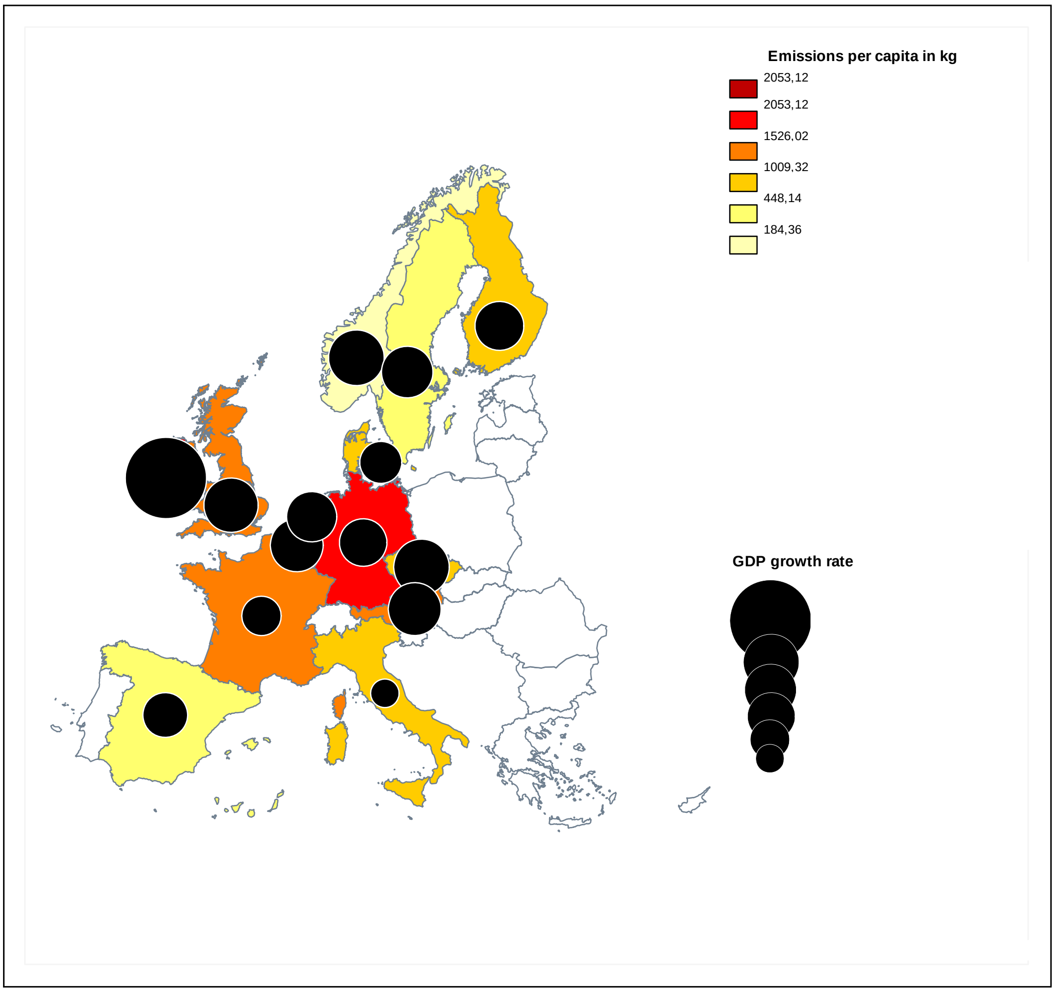

Figure 2: Emissions per capita in 2012 and average GDP growth rate

electricity for heating. In contrast, in Poland, the share of coal is between 40% and 65%, while the UK and the Netherlands use mainly natural gas (nearly 70%).

These characteristics have obviously important consequences on the energy consumption of households. Imposing a homogenous European carbon tax rate would imply geographical differences in the tax burden that could raise inequalities among households. Our contribution relies on the analysis of the potential interregional compensations that European authorities could implement in order to correct for the regressive characteristics of the carbon tax.[5]

This paper relates to two strands of the literature: the first branch of the literature examines the link between economic growth and pollutant emissions; and the second branch looks at the determinants of energy consumption.

[5]For the french case, Bureau (2012) and Senit (2012) conclude that the acceptability of the environmental policies is an important issue.

The first part of the literature analyzes the environmental consequences of economic growth. The relationship between economic growth and pollution was the subject of intense research over the past few decades. Several empirical studies have suggested that there is an inverted U-shaped relationship between income per capita and pollutant emissions (Environmental Kuznets Curve, EKC). Since the beginning of the 1990's, the EKC has become an essentially empirical research issue, following the studies of Grossman and Krueger (1993), but the general conclusions are ambiguous. Many authors claim that there is no evidence supporting the EKC hypothesis and they rather report a monotonically increasing or decreasing relationship between pollution and income per capita (Holtz-Eakin and Selden (1995), Torras and Boyce (1998), Hettige *et al.* (1999), de Bruyn *et al.* (1998), and Roca *et al.* (2001)).

The second branch of the literature analyzes the determinants of the energy demand and the impacts of energy price variations on energy demand, welfare and equity. Most part of the econometric studies usually takes into account revenue and climatic determinants separately. Regarding the interactions between energy demand and incomes, there exists a significant inverted U-shaped relationship (see for instance Ang (1987) or Destais *et al.* (2009)). Conversely, there is no consensus concerning the relations between the climatic variables and the energy demand. Engle *et al.* (1986) find a V-shaped relationship while Bessec and Fouquau (2008) put in light a U-shaped one. Tol *et al.* (2012) combines climatic conditions, revenues and energy prices and find significant impacts of all these variables on carbon emissions.

Our article is close to Tol *et al.* (2012) but we depart from it by simulating the consequences of carbon taxation, in terms of country specific costs and inequalities. Indeed, the environmental taxes often appear to be regressive. Metcalf *et al.* (2008) and Metcalf (2009) consider the possible distributional impacts of carbon taxes in the United States. These studies show that environmental taxes are highly regressive. Wier et al. (2005) confirms the regressive properties of such reforms for the Danish case. Ekins and Dresner (2004) consider the distributional impact of introducing a carbon tax and increasing fuel duty for United Kingdom. It is found that, under some specific and well-designed compensation schemes, a carbon tax can be made progressive, but that the tax would make those currently worst affected by fuel poverty more badly off. Regarding the French case, Bureau (2011) shows that the distributional effects of a carbon tax on car fuels are likely to be regressive before revenue recycling. There has been also extensive work done in the US on the regional distribution of a carbon tax (Hassett *et al.,* 2007, Mathur and Morris, 2012) which partially confirm these inequality consequences.

In this paper, we rely on climatic and economic differences among European countries to enlighten the regressive properties of a carbon tax. This focus distinguishes our paper from related work. The objective is first to measure the effects of the climatic and macroeconomic determinants on the CO_2 emissions of households. Secondly, we rely on the econometric results to measure the consequences of a European carbon tax among heterogeneous countries.

Our investigation is based on non-stationary panel data models. We estimate a long-term relationship between carbon emissions per capita, GDP per capita and energy prices. We simultaneously estimate the corresponding short-term relationship using an error correction modelling approach. Our results show that there is a strong long-term relationship between CO_2 emissions per capita, GDP per capita and energy prices around a slightly decreasing trend. We also show that there is a significant and strong adjustment to disequilibrium. We find that the climatic variables play no role in the long-term, but they represent a key factor explaining emissions in the short-term. Finally, we conclude that the short-term drivers of CO_2 emissions are no longer determinants in the long-term, and *vice versa.* Finally, we compute the local consequences of the carbon tax project on the tax burden. We then show that the carbon tax leads to inequalities in the tax burden, measured by the ratio of "tax revenues over GDP" in each country. We then argue that an environmental tax reform requires specific redistribution among countries. The amount should not be set equal for all countries but should depend on some geographical characteristics. We finally propose a set of compensatory scenarios and policy tools that could correct for the inequalities generated by the environmental tax reform. Hence, the environmental tax could be a feasible policy tool for Europe to fight carbon emissions.

The rest of the paper is structured as follows. Section 2 describes the data used. Section 3 presents the methodological approach and section 4 the empirical findings. Simulation results are presented in section 5. Finally, some conclusions are drawn in the last section.

2 Data

The study is based on a balanced panel data set for a sample of 14 European Countries over the period 1990 to 2012.[6] Data are obtained from various sources which includes Odyssee databases and International Energy Agency. E_{it} for a given country i in year t is the CO_2 emission per capital measured in kilogram (kg) in the residential sector without taking into account electricity.[7] Y_{it} is the GDP per capita in purchasing power parity and constant Euros prices. P^{gas} and P^{oil} are respectively the gas price and heating-oil price in euros per MWh. Then, to measure the climatic conditions, the data on Heating Degree-Day (Hdd_{it}) are used. The actual number of heating degree days is an indicator of the winter severity, and thus of the heating requirement. It is calculated as the sum over each day of the heating period (e.g. October to April) of the difference between a reference indoor temperature (usually $18°C$) and the average daily temperature. For instance, if the average temperature of a day in winter is $5°C$, the number of degree day of that day is 13 degree days ($i.e.$ $18° - 5°$). Higher the number of Degree-Days, higher the severity of the winter. Our final sample consists of 322 observations. The main descriptive statistics are presented in tables 2 and 3.

[6]The countries are Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Spain, Sweden, United Kingdom and Norway.

[7]It is possible to distinguish carbon dioxide emissions due to fossil fuels and carbon dioxide emissions taking into account electricity. In the purpose of the paper, only residential emissions due to fossil fuels are considered.

Table 2: Summary Statistics 1/2

VARIABLES	mean	Standard deviation	Minimum	Maximum
E : Emissions per capita	997.6812	541.2307	62.87769	2570.7
P^{gas} : Gas price	67.35687	45.57887	6.890863	227.4687
P^{oil} : Oil price	54.73867	29.66472	3.266955	154.9605
Y : GDP per capita	27501.99	9093.331	6847.825	54867.58
Hdd : Heating Degree Day	2874.161	820.9973	1481.522	4947

Table 3: Summary Statistics 2/2

	E	Y	P^{gas}	P^{oil}	Hdd
Austria	1096.693	27749.97	66.54879	48.89157	2966.667
Belgium	2053.121	26293.15	60.55539	38.61557	1880.904
CZR	978.4801	9094.789	41.05008	41.21938	3470.516
Denmark	761.2083	35270.9	104.2284	79.23519	3151.565
Finland	448.1357	26475.83	18.72532	46.87147	4360.943
France	1009.32	26393.06	63.23933	48.51241	1956.826
Germany	1448.03	26279.94	70.43976	40.11754	3615.173
Ireland	1677.772	30904.74	67.08443	52.6024	2078.037
Italy	888.6237	23225.62	88.47135	90.94468	1930.793
Netherlands	1220.734	29258.74	69.23572	56.1984	2863.087
Spain	404.6798	18534.16	74.03827	44.44772	1784.939
Sweden	422.6646	30924.98	149.4871	75.51326	3482.348
UK	1373.718	26980.8	48.33538	36.4282	3007.563
Norway	184.3584	47641.2	21.55698	66.74364	3688.894

Huge disparities exist between countries. For example, gas prices in the United Kingdom are only 1.17 times higher than in Czech Republic while that GDP per capita is 2.96 times higher. Figure 3 shows the link between climate variation measured as the difference between HDD and reference HDD and carbon emissions per capita. A positive value means that the number of HDD is higher than the reference value in the year considered. This is a way to measure winter severity. We note a positive relation between cold peaks and emission peaks. For example, in 2006, the winter was very cold and we note a peak of carbon emissions in the same year. The same relation is noticed in 2010. Thus, in a short period, a correlation seems exist between the number of HDD and emissions. However, after each peak, CO_2 emissions fluctuate around their trend.

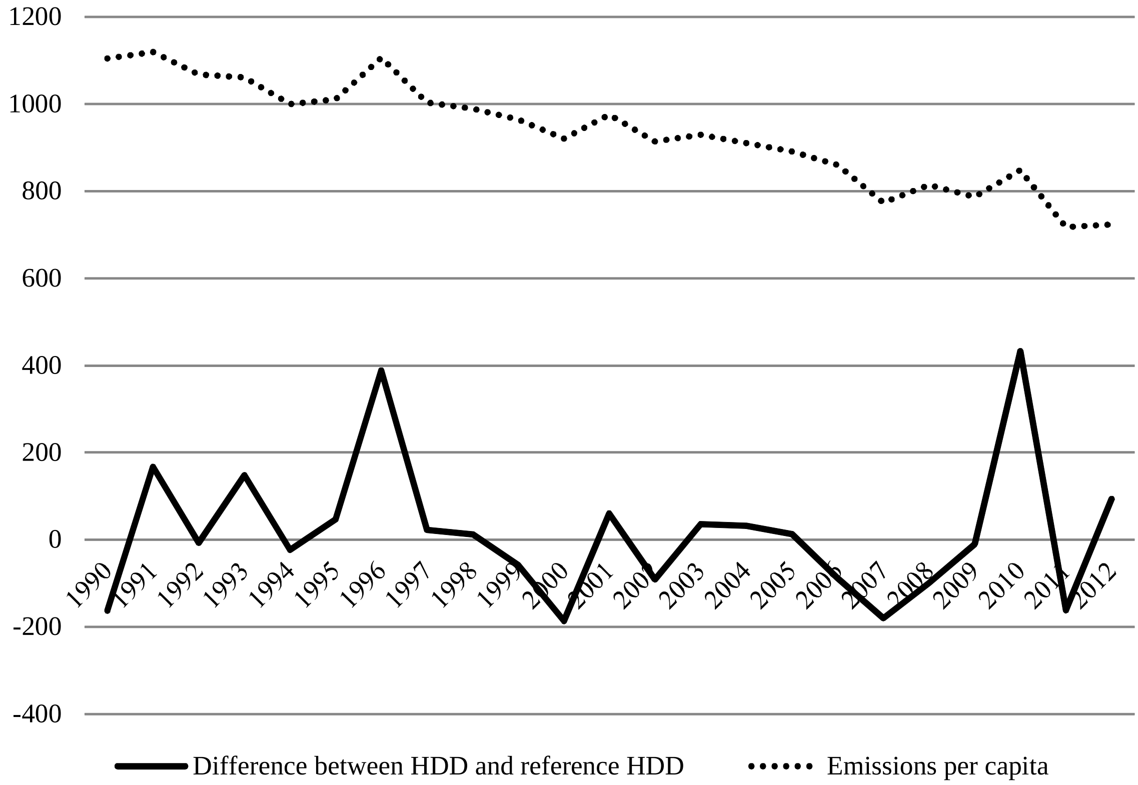

Figure 3: Winter severity and emissions per capita

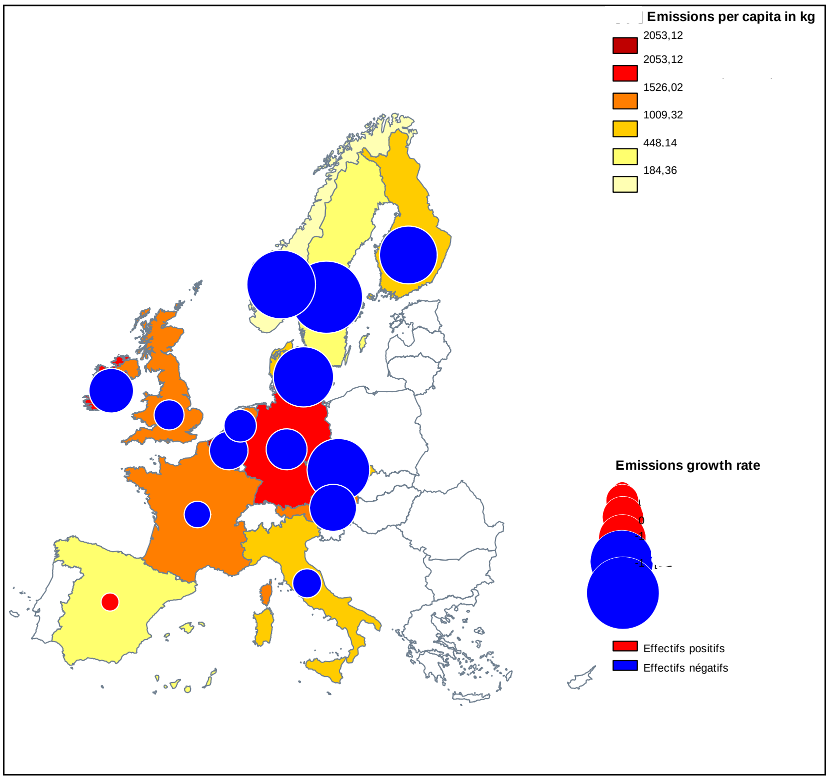

Figure 4: Emissions per capita in 2012 and average emissions growth rate

We also note some disparities between northern countries (Sweden, Norway, Finland and Denmark) and the rest of Europe. Northern countries have the lowest level of CO_2 per capita emissions in 2012 and recorded the highest decrease of emissions over the period (Figures 4 and 5). These countries have also introduced a carbon tax between 1990 and 1992. Testing the effect of a carbon introduction in these countries seems irrelevant. Considering these arguments, from now, our analyses are conducted separately for these 4 countries.

3 The empirical model

We here aim to model the relationship between per capita carbon dioxide emissions in the residential sector and their determinants. Insofar as income and heating are the key determinants of energy use in residential sector we extend an empirical model of energy consumption by Ang (1987). We Estimate a non-stationary dynamic panel in which parameters are heterogeneous across groups. The model considers linear relationship between carbon emissions and GDP. We extend the model by adding a climatic variable and energy prices. We rely on the recent literature on non-stationary panel data. We first apply various panel unit root tests (both first and second generation tests) to our variables and their first differences in order to assess the order of integration of each variable. The results guide the next stage of modelling. Indeed, the variables in level

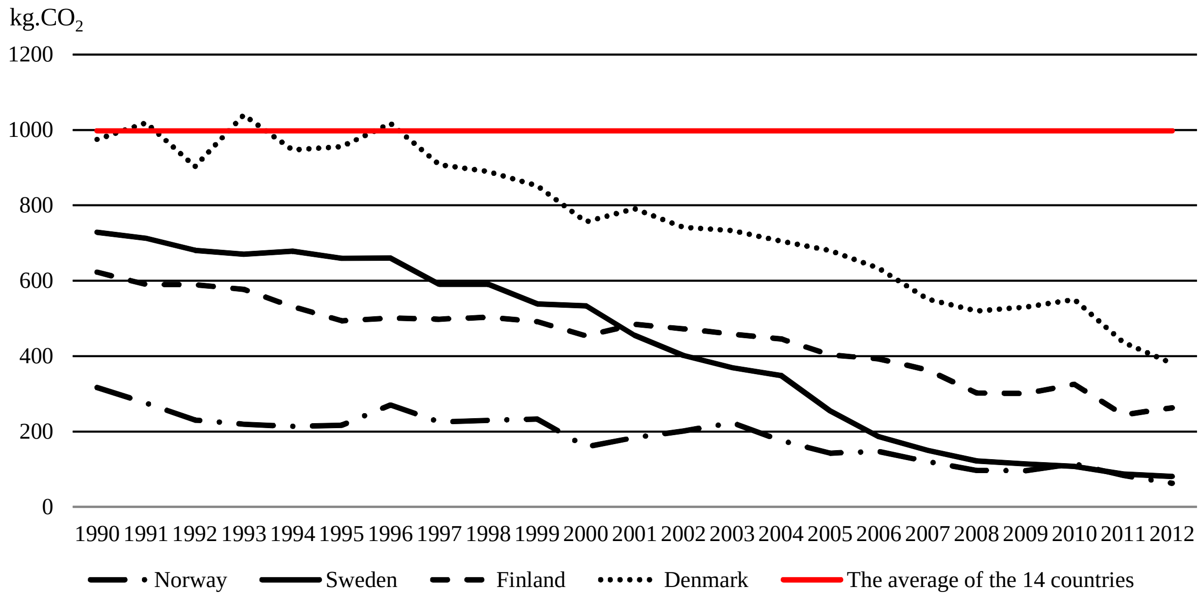

Figure 5: Evolution of CO2 emissions in Northern countries

integrated at order 1 (Emission per capita, GDP per capita and energy prices) are considered in the long term equation. This choice is further supported by the results of various panel cointegration tests. The first generation cointegration tests by Pedroni (2001) and the second generation cointegration test by Westerlund (2007) confirm the existence of cointegration (a long term) relationship between emission per capita, GDP per capita and gas and heating-oil prices. Moreover, panel unit tests results on the climatic variable heating degree days indicate that this variable is stationary. Hence, we will consider this variable in the short term equation. This short term equation includes the lagged first differences of determinants considered in the long term equation and an error correction term representing the return towards long term equilibrium. We start with a (very) general long-run model:

$$E_{it} = \alpha_{0i} + \beta_i t + \alpha_{1i} Y_{it} + \alpha_{2i} P_{it}^{gas} + \alpha_{3i} P_{it}^{oil} + \alpha_{4i} P_{it}^{gas} P_{it}^{oil} + \varepsilon_{it}$$

Alongside a (general) short-term model (with an error-correction equation):

$$\Delta E_{it} = \delta_{0i} + \phi_i \varepsilon_{it-1} + \delta_{1i} \Delta Y_{it-1} + \delta_{2i} \Delta P_{it-1}^{gas} + \delta_{3i} \Delta P_{it-1}^{oil} + \delta_{4i} Hdd_{it} + \mu_{it}$$

$i = 1, .., 15; t = 1, .., 23$ where subscript i refers to the country and t to the time period. E is the logarithm of per capita CO_2 emissions in the residential sector, Y the logarithm of per capita GDP, P^{gas} and P^{oil} the logarithms of gas price and heating-oil price respectively, Hdd the heating degree day (as a measure of the temperature). One significant advantage conferred by panel data is controlling for unobserved heterogeneity. ϕ is the speed of adjustment term. If $\phi_i = 0$, then there would be no evidence for a long-run relationship.

Table 4: Panel unit-root test results

Test	IPS				Hadri			
Series	Level		Variation		Level		Variation	
Model	trend	const	trend	const	trend	const	trend	const
Emission per capita	-0.413	6.304	-13.443***	-15.390***	15.558***	33.233***	-2.166	0.490
GDP per capita	4.755	-0.598	-4.961***	-6.153***	24.719***	47.091***	5.891***	7.280***
Gas price	0.302	5.850	-8.786***	-10.456***	23.825***	37.515***	0.831	1.282
Heating-oil price	-3.100***	6.758	-9.110***	-11.966***	16.016***	45.754***	-2.719	-0.522
Heating Degree days	-9.175***	-11.205***	-10.106***	-14.008***	0.540	2.771***	-3.492	-3.381

Note: *, ** and *** refer respectively to the rejection of the null hypothesis at 10%, 5% and 1% significance levels. IPS tests the null hypothesis that all panels contain unit-root against the alternative that some panels at least are stationary. Hadri tests the null that all panels are stationary against the alternative that some panels are non-stationary.

3.1 Panel unit-root tests

The literature on panel data econometrics with integrated data and more specifically on panel unit root and panel cointegration tests has experienced rapid development in recent years. It distinguish between the first generation tests based on the assumption of inter-individual independence of panel units, and the tests of the second generation, accounting for various form of individual inter-dependencies. More recently, this literature proposed testing procedures that allows for both structural breaks and cross-section dependence.

To determine the order of integration of our series (Emission per capita, GDP per capita, Natural gas price, Heating oil price and Heating degree days), in our panel of European countries, we use successively unit root tests of the first generation proposed by Im, Pesaran and Shin (2003) and Hadri (2000). and the second generation unit root test proposed by Pesaran (2007). We perform these different tests on variables in level and in first difference.

The test by Im, Pesaran and Shin (2003) tests the null hypothesis that all panels contain unit roots against the alternative that some panels are stationary with heterogeneous autoregressive root less than unity for each country. Thus, in case of rejection of the null hypothesis, we can deduce that one country panel at least does not have a unit root and is therefore stationary. The test statistic, called W-t-bar, is well suited for small sample and obtained from the individual ADF statistics. The test by Hadri (2000) tests the null hypothesis that all panels are stationary against the alternative that some panels contain unit-roots. It is an extension of the KPSS test proposed in the time series econometric literature. It is a Lagrange Multiplier (LM) test where the null and the alternative hypotheses are reversed. This test is useful to help confirm or deny conclusions based on tests with the null hypothesis being non-stationarity.

The results are reported in Table 4 and suggest that the series of Emission per capita, GDP per capita, Gas price and Heating-oil price are all integrated of order 1 in our panel. The series Heating degree days is stationary.

Table 5: Pesaran's panel unit-root test results

Series	Level		Variation	
Model specification	trend	const	trend	const
Emission per capita	-3.252***	-2.701***	-5.042***	-5.128***
GDP per capita	-2.325	-1.761	-3.376***	-3.095***
Gas price	-2.438	-1.589	-4.566***	-4.495***
Heating-oil price	-2.289	-2.084*	-4.305***	-3.943***
Heating Degree days	-3.302***	-3.099***	-4.844***	-4.905***

Note: Pesaran tests the null hypothesis that all panels contain unit-root against the alternative that some panels at least are stationary. *, ** and *** refer respectively to the rejection of the null hypothesis at 10%, 5% and 1% significance levels. The test reject the null hypothesis when the test statistic CIPS is lower than the critical value. For our sample the corresponding critical values at 10%, 5% and 1% significance level are respectively: -2.60, -2.70 and -2.89 for the CADF model including a constant and trend; -2.07, -2.17, -2.34 for a model with constant.

As there are sound arguments to suspect cross-sectional dependencies between European countries considered in our panel, we check the robustness of panel-unit root tests results using panel unit-root by Pesaran (2007). The test statistic ICPS is computed from a Cross Sectionally Augmented Dickey Fuller (CADF) model. The test accommodates for both cross sectional dependence and serial correlation. The results are reported in Table 5 and confirm previous panel test results in Table 4 except for Emission per capita. Indeed, the Pesaran test reject the null hypothesis in favor the alternative that some panels at least are stationary. When we exclude Northern European countries from our panel, the Pesaran test no more reject the null hypothesis that Emission per capita contains a unit-root. We can conclude that for a selected panel of European countries that exclude northern countries, the series Emission per capita, GDP per capita, Gas price and Heating-oil price are all integrated of order one.

3.2 Panel cointegration tests

The use of panel cointegration tests for the presence of long-run relationships among integrated variables has received much attention recently. We choose the first generation residual-based panel cointegration test by Pedroni (2001) and the second generation test for error correction in panel by Westrlund (2007). Westrlund (2007) suggest four statistics (Ga, Gt, Pa, Pt) to test for the absence of cointegration by determining whether there exists error correction for individual panel members or for the panel as a whole. The Ga and Gt test statistics test the null hypothesis that the speed of adjustment toward equilibrium is zero for all panel units versus the alternative that the speed of adjustment is negative at least for one panel unit. Rejection of the null should therefore be taken as evidence of cointegration of at least one of the cross-sectional units. The Pa and Pt test statistics pool information over all the cross-sectional units to test the null hypothesis that the speed of adjustment toward equilibrium is zero for all panel units against the alternative that the speed of adjustment is negative for all panel units. Rejection of the null should therefore be taken as evidence of cointegration for the panel as a whole. The test allow for cross sectional dependence by bootstrapping robust critical values.

4 Estimation results

Table 6 reports the estimation results of four models. Models (1) to (3) are nested in the more general model (4). In these models, all of the estimated coefficients which are significant at conventional levels have the expected sign. The estimated parameters in all models are comparable and not significantly different, which is an evidence of the robustness of our results. In a first step, we test the hypothesis of slope homogeneity through a comparaison between the Mean Group estimator (MG) and the Pooled Mean Group estimator (PMG). The calculated Hausman statistic is 2.35. Here we conclude that the PMG estimator, the efficient estimator under the null hypothesis, is preferred. Long-run elasticities are equal across all panels. There is a slope homogeneity (see Pesaran and Smith, 1995).

Table 6: Estimation results

Model	(1)	(2)	(3)	(4)
VARIABLES	Coefficient (Std. Err.)	Coefficient (Std. Err.)	Coefficient (Std. Err.)	Coefficient (Std. Err.)
Equation 1: Long term equilibrium				
GDP	0.218*** (0.0649)	0.590*** (0.0942)	0.146** (0.0577)	0.560*** (0.0850)
GAS PRICE	-0.139*** (0.0172)	-0.0374*** (0.0141)	-0.319*** (0.0550)	-0.316*** (0.0750)
OIL PRICE	-0.111*** (0.0207)	-0.126*** (0.0157)	-0.248*** (0.0388)	-0.338*** (0.0587)
GAS x OIL			0.0447*** (0.0117)	0.0619*** (0.0164)
t		-0.0119*** (0.00203)		-0.0106*** (0.00178)
Equation 2: Short term dynamics				
ϕ	-0.660*** (0.0943)	-0.591*** (0.110)	-0.684*** (0.0961)	-0.620*** (0.105)
HDD	0.588*** (0.0769)	0.540*** (0.0772)	0.599*** (0.0768)	0.551*** (0.0781)
Intercept	-0.811 (0.579)	-3.141*** (0.546)	0.114 (0.608)	-2.405*** (0.505)
Obs	220	220	220	220
LL	383.9238	390.3617	388.4278	395.9493

ϕ is significantly negative that underline a long-run relationship. In the output, the estimated long-run GDP per capital elasticity is significantly positive. A 1% increase in GDP per capita, all things being equal, will result in an increase of 0.56% in CO_2 emission per capita in residential sector. The prices elasticities are significantly negative. the estimated parameter of the energy price cross-term is positive and reflect a trade-off between the use of gas and heating-oil by households in the long-term.

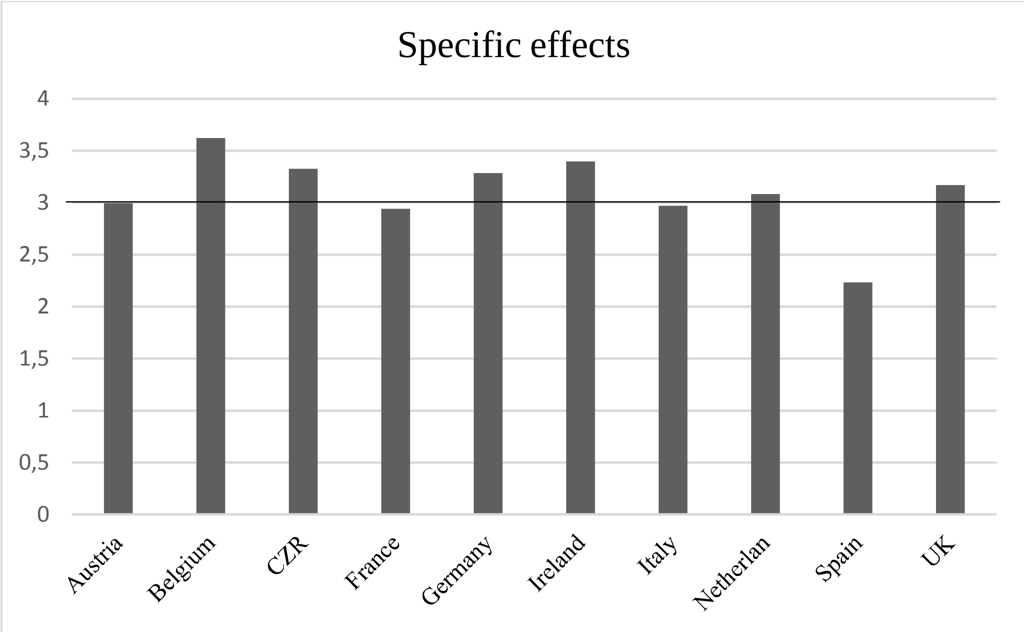

Figure 6: Specific effects

Table 7: Short terme stimation results for Northern European Countries

VARIABLES	Coefficient	(Std. Err.)
HDD	0.901**	(0.206)
Intercept	-7.457**	(1.693)
Observations	88	
Number of Countries	4	
R-squared	0.287	
Note: estimations are realized only on Norway, Sweden, Finland and Denmark.		
Standard errors are in (); *, ** and *** refer respectively to the 10%, 5% and 1% significance levels.		

Panel data analysis allow to control for regional unobserved heterogeneity and the random effects modelling assumes no-correlation between the unobserved heterogeneity and the explanatory variables. Hence, in our case, specific regional effects are not correlated with regional GDP, regional technologies, energy prices nor the climatic variables. Figure 6 presents the specific regional effects and shows that on average, all things being equal, people in Belgium, Germany, Ireland, emit more than people living in other regions. Similarly, inhabitants of Finland, Sweden or Norway are less emitters. These specific effects may be explained by the average area of housing per capita and/or the quality of the thermal insulation of housing or simply by the degree of sensitivity to the cold of inhabitants.

5 Simulation

We assume that a carbon tax of 20 € per ton is implemented in 2012 in European countries. We predict and analyze the impacts of this policy on income and CO_2 emissions in each country. In a first step, we use the results in table 4 to assess the impacts of the carbon tax on the national emissions (Table 8). We also measure the burden of the policy by computing the national tax revenues to GDP ratio. We observe huge inequalities between countries. For example the Czech Republic contributes for 0.13% of its GDP and France contributes only for 0.06% (Table 10). In order to correct these regressive consequences, we propose some fiscal policy adjustments that should be made to ensure tax fairness: *(i)* we compute which level of carbon tax rate should be applicable if the criterion of an equal abatement effort among each country is considered (Table 9); *(ii)* we propose a downstream fiscal policy adjustment that consists in the implementation of a uniform carbon tax of 20€ per ton with lump sum redistribution insuring tax *ex-post* fairness (Table 10).

Not surprisingly, the introduction of a carbon tax reduces CO_2 emissions in all countries, but with significant differences (Table 8). In average, countries' abatement effort are around 0.5%, but this reduction is equal to -0.18% in Italy and -0.65% in the UK. More in details, the abatement rates are not the same across countries. United Kingdom and Belgium record the highest rates of abatement while Ireland and Italy record the lowest abatement rates. These differences are probably due to the fact that Ireland is one of the highest emitters in Europe and Italy has already imposed high levels of energy taxes.

Table 8 : Carbon emissions with and without tax

	Carbon emissions per capita without tax	Carbon emissions per capita with a 20€ carbon tax	Abatement (in %) with a 20€ carbon tax
Austria	963.6	959.33	-0.4451023
Belgium	1723.8	1715.2	-0.5013993
CZR	753.12	749.48	-0.4856701
France	861.48	857.3	-0.4875773
Germany	1261.18	1255.2	-0.4764181
Ireland	1532.1	1526	-0.3997379
Italy	763.19	761.8	-0.1824626
Netherlands	1060.8	1055.9	-0.4640591
Spain	341.37	339.92	-0.426571
UK	1126.2	1118.9	-0.6524265

By requiring an equal level of abatement rate, Italy should increase significantly the amount of the carbon tax and should introduce a carbon tax of 51.5€. Conversely, United Kingdom could decrease the carbon tax rate to 13€. Most countries would see the level of their carbon tax rates fall below 20€ (Table 7). However, this observation must be taken carefully. Imposing a carbon tax of 50€ in Italy could be unfair if we consider the standard of living in this country, which is probably lower than in the United Kingdom for example.

Table 9 : Carbon emissions target with an equal abatement		
	Target of carbon dioxide emissions if abatement rate of each country is equal to the average panel abatement rate	Amount of tax to reach the target (with an equal abatement rate)
Austria	959.4978975	19.16
Belgium	1716.461681	16.901
CZR	749.9139234	17.481
France	857.8126284	17.394
Germany	1255.811082	17.968
Ireland	1525.577759	21.614
Italy	759.9410548	51.523
Netherlands	1056.284111	18.318
Spain	339.9167676	20.025
UK	1121.4057	12.926

When the policy consists in a lump-sum redistribution of the tax revenues, we show that most countries (8) have to contribute positively, in addition to their environmental contribution. For instance, French households have to pay 7.74€ per capita and per year, which is significant. In comparison, the average cost per capita of the climate policy in Europe is about 160€ per capita per year. Obviously, Belgium is the main receiver (8.82€ per capita per year). If the Government decides to implement a heterogeneous carbon tax rate, we observe the same European ranking.

Table 10: Abatement per capita for an equal abatement rate (tax revenue/GDP)

	Tax revenue per capita with a 20€ carbon tax	Contribution rate (tax revenue/GDP %) with a 20€ carbon tax	Lump redistribution per capita with a contribution rate (tax revenue/GDP) equal between panel countries
Austria	19.1866	0.059538	-8.625029174
Belgium	34.304	0.1161739	8.820531158
CZR	14.9896	0.1311782	5.127920595
France	17.146	0.0594512	-7.743967812
Germany	25.104	0.0816564	-1.428326785
Ireland	30.52	0.0836542	-0.966122904
Italy	15.236	0.065374	-4.877531583
Netherlands	21.118	0.0646192	-7.086201152
Spain	6.7984	0.0344167	-10.24905192
UK	22.378	0.0740652	-3.697321499

6 Conclusion

In this article, we have highlighted the geographical heterogeneities among the European countries and the consequences of the implementation of a carbon tax. We have shown that imposing a homogenous carbon tax rate implies geographical differences in the tax burden that raise inequalities among households. We analyzed different compensation schemes that European Governments may implement in order to correct the regressive characteristics of the carbon tax. We have shown that a region-specific carbon tax instead of a homogenous national tax compensate these inequalities. We have simulated two alternative policy options: i) a downstream policy that consists in regional lump-sum redistribution and ii) an upstream policy imposing differentiated regional carbon taxes. We have compared these policies in terms of emission abatement and concluded that the lump-sum redistribution policy is more efficient. Moreover, such policy is likely the costless way to implement the environmental policy without compromising its social acceptability.

References

[1] B.W. Ang. A cross-sectional analysis of energy-output correlation, Energy Economics, 9, 274-286, 1987.

[2] M. Bessec and J. Fouquau, The non-linear link between electricity consumption and temperature in Europe: A threshold panel approach, Energy Economics, 30(5), 2705-2721, 2008.

[3] G. Destais, J. Fouquau and C.Hurlin, Energy Demand Models : A Threshold Panel Specification of the "Kuznets Curve", Applied Economics Letters, 16(12), 2009.

[4] S.M. de Bruyn, J.C.J.M. Van den Bergh, and J.B. Opschoor, Economic growth and emissions: reconsidering the empirical basis of environmental Kuznets curves, Ecological Economics, 25, 161–175, 1998.

[5] B. Bureau. Distributional effects of a carbon tax on car fuels in France, Energy Economics, 33, 121-130, 2011.

[6] D. Bureau, The political economy of the 2009 French carbon tax project, Working Party on Integrating Environmental and Economic Policies, OECD, 2012.

[7] J.H. Dreze and E. Malinvaud, Growth and employment: The scope of a European initiative, European Economic Review, 38(3/4), 489-504, 1994.

[8] P. Ekins and S. Dresner. The Distributional Impacts of Economic Instruments to Limit Greenhouse Gas Emissions from Transport, Policy Studies Institute, 2004.

[9] R. Engle, C. Granger, J. Rice and A Weiss, Semiparametric Estimates of the Relation Between Weather and Electricity Sales, Journal of the American Statistical Association, 81 (394), 310-320, 1986.

[10] European Commission, Growth, competitiveness, employment - The challenges and ways forward into the 21st Century. White Paper, 1993.

[11] G.M. Grossman and A.B. Krueger. Environmental Impacts of a North American Free Trade Agreement In The Mexico-U.S. free trade agreement, P. Garber, ed. Cambridge, Mass.: MIT Press, 1993.

[12] Hadri, K. Testing for stationarity in heterogeneous panel data. Econometrics Journal, 3, 148-161, 2000.

[13] Hassett, K.A., A. Mathur, and G.E. Metcalf. The Incidence of a U.S. Carbon Tax: A Lifetime and Regional Analysis. NBER Working Paper. Cambridge, MA: National Bureau of Economic Research, 2007.

[14] H. Hettige, M. Mani and D. Wheeler, Industrial pollution in economic development: Kuznets revisited. In P. (Ed.), "Trade, Global Policy and the Environment", World Bank Discussion Papers, Vol. 402, 1999.

[15] D. Holtz-Eakin and T.M. Selden, Stoking the fires? CO_2 emissions and economic growth, Journal of Public Economics, 57, 85-101, 1995.

[16] Im, K. S., M. H. Pesaran, and Y. Shin. Testing for unit roots in heterogeneous panels. Journal of Econometrics, 115, 53-74, 2003.

[17] Mathur, A., and A.C. Morris. Distributional effects of a carbon tax in broader U.S. fiscal reform. Climate and Energy Economics Disucssion Paper, Washington DC: The Brookings Institution, 2012.

[18] G.E. Metcalf. Designing a Carbon Tax to Reduce U.S. Greenhouse Gas Emissions, Review of Environmental Economics and Policy, 2009.

[19] G.E. Metcalf, J.F. Holak, H. Jacoby, S. Paltsev, and J. Reilly. Analysis of U.S. Greenhouse Gas Tax Proposals. NBER Working Paper No. 13980, 2008.

[20] OECD, Effective Carbon Prices, OECD Publishing, Paris, 2013. DOI: http://dx.doi.org/10.1787/9789264196964-en

[21] Pedroni, P. Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors. Oxford Bulletin of Economics and Statistics, 61, 653-670, 1999.

[22] Pedroni, P. Purchasing Power Parity Tests in Cointegrated Panels. Review of Economics and Statistics, 83, 727-731, 2001.

[23] Pesaran, M. H. A Simple Panel Unit Root Test In The Presence Of Cross-section Dependence. Journal Of Applied Econometrics 22, 265–312, 2007.

[24] Pesaran, M.H. and R.P. Smith. Estimating long-run relationships from dynamic heterogeneous panels. Journal of Econometrics, 68, 79-113, 1995

[25] J. Roca, E. Padilla, M. Farré, M. and V. Galletto, Economic growth and atmospheric pollution in Spain: Discussing the environmental Kuznets curve hypothesis, Ecological Economics, 39, 85-99, 2001.

[26] C-A. Senit, The politics of carbon taxation in France: preferences, institutions, and ideologies, Working paper N°20/12, IDDRI SciencesPo, 2012.

[27] R.S.J. Tol, S. Petrick, K. Rehdanz.The Impact of Temperature Changes on Residential Energy Use. University of Sussex, Economics Department Working Paper Series, No.44-2012, 2012.

[28] M. Torras and J.K. Boyce, Income, inequality and pollution: a reassessment of the environmental Kuznets curve, Ecological Economics, 25, 147–160, 1998.

[29] J. Westerlund, Testing for error correction in panel data. Oxford Bulletin of Economics and Statistics 69: 709–748, 2007.

[30] M. Wier, K Birr-Pedersenb, H. K. Jacobsenc, J. Klok. Are CO_2 taxes regressive? Evidence from the Danish experience, Ecological Economics, 52, 239-251, 2005.