Clean Energy Industries and rare Earth Materials: Economic and Financial Issues

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Abstract

In the last few years Rare Earth Materials (REMs) prices have experienced a strong increase, due to geopolitical policies and sustainability issues. Provided that these materials at risk of supply disruptions are largely employed in the development of new technologies - such as clean energy industries - financial markets may already have included these concerns into clean energy companies evaluation. We use a multifactor market model for the period January 2006-September 2012 to analyse the impact of REMs price changes – specifically Dysprosium and Neodymium - to six clean energy indexes (NYSE-BNEF) tracking the world's most active quoted companies in the clean energy sector. Results show that during period of price increase there is a negative relation between REMs price changes and the stock market performance of clean energy indexes, specifically wind. The European clean energy index is also negatively affected and this may be relevant to policy makers considering that Europe is putting in place some relevant policy actions to support the development of the clean energy sector.

Keywords: Clean energy, rare earth materials, stock prices

JEL classification: Q56, Q33, G11, C58, E39

1 Introduction

Clean energy, with double-digit growth rates and competition spanning Europe, Asia and the Americas is a dynamic and forward-looking industry. Rare Earth Materials (REMs) – as Dysprosium, Neodymium, Terbium, Yttrium- are largely employed in the development process of new technologies such as clean energy industries. Until now, 97% of the global supply of these metals is produced in China, that has recently experienced a period of copious cuts of its exports, apparently in order to protect its environment. This fact has greatly increased REMs prices (300/700%), causing tension and uncertainty among the world clean energy markets.

From an economic perspective, the China Raw-Materials case and the strong increase in prices imply that the supply of REMs by clean energy industry is becoming more and more difficult because of REMs increasingly reduced availability. This problem principally affects Europe, that does not extract REMs from its subsoil and, consequently, is fully dependent on imports.

From a financial point of view, REMs prices may influence green energy stock prices. Provided that the clean energy industry is based on the use of these materials at risk of supply disruptions, financial markets could already include these concerns into clean energy companies' valuation. Indeed, the fundamental value of firms and, in turn, stock prices, are determined by macro and microeconomic variables. Among them, raw materials, such REMs, may play a relevant role in determining the performance of clean energy firms and, to some degree, in determining investment performance, opportunities for stock markets and the overall global low carbon economics and political strategy.

The aim of this paper is to analyze the impact of REMs price trends on the share price value of clean energy companies measured by a new family of Clean Energy Indexes. Specifically, we focus our analysis on Dysprosium and Neodymium, that are considered more critical materials compared to the other REMs (DOE, 2010).
To this end, we use a multifactor market model based on the theory of Capital Asset Pricing Model (CAPM), that supposes that stock prices return is associated with movements of some common factors. We apply this model to three clean energy sectors specific indexes and three regional clean energy indexes. These indexes are produced by The New York Stock Exchange (NYSE) and Bloomberg New Energy Finance (BNEF) and track the world's most active, quoted companies in the clean energy industry. The sector specific indexes include companies active in the wind, solar and energy smart technologies, whereas the three regional indexes include companies active in the Americas; Europe, Middle East and Africa; Asia and Oceania. We use daily data from January 2006 to September 2012.
The novelty in this work is threefold. Firstly, the paper provides an overview of a topic that has not yet been empirically investigated but that will be of outmost importance in the next future. Secondly, it performs the first econometric analysis of the effects of REMs on clean energy corporate value using a multifactor market model. Finally, the paper presents the first use of the NYSE-BNEF Clean Energy Indexes in an academic context, presenting this databank to the wider research community through one of the uses that can be made of this resource.
The paper is organizes as follows: Section 2 highlights the debate about rare heart materials, Section 3 focuses on the multifactor market model, Section 4 presents data and the empirical model, Section 5 reports the results, Section 6 concludes.

2 Clean energy and REMs

In order to tackle climate change, to increase energy supply security and to foster the sustainability and competitiveness of the economy, many countries have set up a regulatory framework oriented to increase the diffusion of the clean energy sector. In the latest year the installed capacity of the renewable technologies grew very rapid. In the five year period 2006 – 2011 the average annual growth rate of solar photovoltaic (PV) was equal to 58%, followed by concentrating solar thermal power (37%) and by the wind power with 26% (REN21, 2012).
During 2011 almost half of the new electricity capacity installed worldwide was renewable based, specifically within the power sector wind and solar photovoltaic accounted respectively for almost 40% and 30% of new renewable capacity installed in 2011, followed by hydropower with about 25% (REN21, 2012).
Globally, form 2004 to 2011 the new investment in renewable energy rose by 395%, passing from 39.5 to 257.5 billion dollars (UNEP, 2012). The rising interest in renewable energy and the grate policies effort in place to support such investments that, according to a GSI (2010) study recent estimates in OECD countries is equal to 27 and 20 US billion dollars/year respectively for renewable energy (excluding hydroelectricity) and biofuels, has stimulated the interest in the study of the market of the input material used in clean energy technology.

Among the different input materials used in low carbon technologies the Rare Earth Materials (REMs) [1] are considered the more critical both in terms of supply risk and importance to clean energy industries (DOE, 2010).
Specifically, some REMs play an important role in many clean energy technologies like: permanent magnets, used in wind turbines and electric drive vehicles; batteries, used in vehicles with electric drive trains; thin films, used in photovoltaic (PV) cells; phosphors, used in fluorescent lighting. They are also largely employed in a wide range of technologies, and are critical input in several applications like: computer hard-drivers, cell phone; fiber optics, lasers, numerous defence applications (such as guidance and control systems and global position systems).
As outlined before market forces and the regulatory framework are likely to cause a large increase in clean energy technologies over the next future, rising as a consequences REMs demand.
However, some geopolitical events could influence the sector. Specifically, the major world producer of REMs is China[2], about 97% of REMs oxides produced worldwide derive form China's mines (Tab. 1) and, in term of value, the major importers of China products are Japan (66%), U.S. with 7%, Europe (Germany and France) with 11%, South Korea and Hong Kong respectively with 3% and 4% and rest of the World with 9% (CRS, 2012).

Table 1. *World Mine Reserves and 2011 Mine Production of REE*

	Reserves[1] (of REE oxide)		***Production***	
	tons	***%***	***tons***	***%***
United States	*13,000,000*	*11.4%*	*-*	*0.0%*
Australia	*1,600,000*	*1.4%*	*-*	*0.0%*
Brazil	*48,000*	*0.0%*	*550*	*0.4%*
China	*55,000,000*	*48.3%*	*130,000*	*97.3%*
Commonwealth of Independent States (CIS)	*19,000,000*	*16.7%*	*na*	
India	*3,100,000*	*2.7%*	*3,000*	*2.2%*
Malaysia	*30,000*	*0.0%*	*30*	*0.0%*
Other Countries	*22,000,000*	*19.3%*	*na*	
World Total (rounded)	***113,778,000***	***100.0%***	***133,580***	***100.0%***

Sources: USGS Mineral Commodities Summaries, 2012
[1]) Part of the reserve base which could be economically extracted (USGS).

With the aim to regulate rare earth production and stabilize prices Chinese government has recently introduced and implemented a series of policies on mining activity. Some of them are oriented to increase internal control and the overall industrial policy program, while other are more oriented to influence global supply and prices. Citing environmental issues related to mining activity and internal demand concerns, China began a reduction in REMs export (Fig. 1). From 2006 China started to introduce an increasing export duty rate, passed for most of them from 10% to 15%-25%, a reduction on quota exported, -117% from 2006 to 2011 and licensing requirements. As a result, the monopolistic status of Chinese REMs

[1] The Rare Earth Materials includes 17 metals of which eight of them are classified as light (LREMs) and the other nine as heavy (HREMs). According with the International Union of Pure and Applied Chemistry the LREMs are: Scandium, Lanthanum, Cerium, Praseodymium, Neodymium Promethium, Samarium and Europium. The HREMs are: Yttrium, Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Thulium, Ytterbium and Lutetium.
[2] From 1940s to the mid of 1980s United States was the leading producer of rare earths providing the majority of these minerals to the rest of the world. From 2002 U.S. mine (Mountain Pass California) stopped extraction; just in the last years the mining activity was resumed.

supply caused cheaper prices within China's borders an unprecedented increase of REMs prices in the world market especially throughout 2009, 2010, and during the first three quarters of 2011 (CRS, 2012)[3].

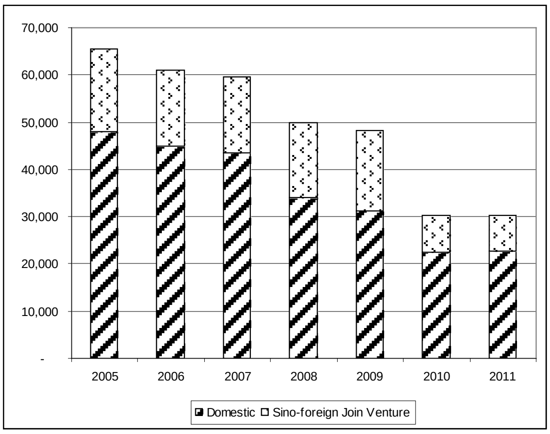

Figure 1. China's export quotas on rare earths (domestic and Sino-foreign JV)
Sources: USGS, 2011,2012

In the meantime, Chinese REMs policy do not imposes quota or export taxes, and often no value-added taxes, for most industrial products manufactured within China border, stimulating many foreign companies to move production to China to get cheaper access to the REMs (Bradsher, 2011). The Chinese REMs policy was strongly condemned by the major commercial partner and a WTO dispute is still in progress (Baroncini 2012; Gu 2011).
Among the seventeen rare metals, two of them are particularly relevant in respect to clean energy sector: Dysprosium and Neodymium. From a technical point of view the magnetic property of these materials make them particularly desirable for the production of new generation of permanent magnets for wind turbine and hybrid electric vehicles[4]. According to the DOE (2010) classification of REMs in relation to 'supply risk' and 'importance to clean energy' these two metals appear particularly critical rising the highest score both in short-term (0-5 years) and in medium-term (5-15 years) period. Future adoption of these materials in low carbon economy may result in a disproportionate increase in the demand that, under certain conditions, over the next 25 years might rise more than 700% and 2600% respectively for Neodymium and Dysprosium (Alonso et al., 2012).
All the above mentioned studies raise the debate about potentials and criticalities of REMs; however, the topic is still heavily underinvestigated and no empirical evidences are available to shed light on the issues behind the link between clean energy and rare materials.

[3] Some specialist attribute part of the export quota reduction to the diplomatic dispute between Japan and China related to the sovereignty over the Diaoyu or Senkaku Islands. Indeed in September 2010 the dispute worsened subsequent to the imprisonment by the Japanese authorities of the captain of a Chinese vessel fishing in the waters of the Islands.

[4] Specifically, they consist of NdFeB (neodymium-iron-boron) plus other intermetallic alloy, like Dysprosium, used to increase efficiency at high temperature. A high intensity generators of wind turbine contain approximately 186 Kg/MW of Neodymium and 24 Kg/MW of Dysprosium (Shih et al. 2012).

3 The multifactor market model

As the amount of money invested in the clean energy sector continue growing, it is important to have a better understanding of the financial mechanisms behind clean energy companies and of the dynamic of the stock prices. For example, clean energy stocks are the object of green funds investments and an analysis of the factors affecting their profitability may be useful for investment decisions and portfolio diversification strategy. Moreover, equity and venture capital investments in alternative energy technologies, other than public expenditures, are an important source of funding for stimulating patenting and research in this area.

Since asset prices can be viewed as a stream of expected discounted cash flow and factors affecting price changes are related either to changes in expected cash flows or to changes in discount rates, different factors can affect stock prices and, thus, stimulates or discourages investments in the clean energy industry.

We argue that REMs prices may be one of these factors, so far greatly understudied, and we believe that a better understanding of the relationships between clean energy stock prices and REMs is critical to understand the development of the alternative energy industry in the years to come.

We use a multifactor market model to analyze the effect of REMs price changes on the stock market performance of the clean energy industry.

Multifactors models are an extension of single-factor CAPM models[5]; in addition to the market factor, those financial models employ multiple factors to explain the performance of a security or a portfolio of securities (e.g. an index) (Fama and French 1993, Fama and French 1996, Chen 2009, Menike 2006, Muradaglu et al 2001, Singh et al 2011). The general form of a multi-factor model is:

$$R_{it} = a_i + b_{i1} F_{1t} + b_{i2} F_{2t} + \ldots + b_{ik} F_{kt} + e_{it} \quad \text{with } t = 1,\ldots,T$$

Where:

F_{kt}: factor k

B_{ik}: sensitivity of the returns on stock i to changes in factor k

e_{it} : random component, with mean $E(e_{it})=0$ and variance $var(e_{it})=\sigma^2$.

In recent years, empirical literature has analysed the relationship between clean energy stock prices and macro-economic variables using multifactor market models (Sadorsky 2001a, 2001b; Henriques and Sadorsky 2008; Kumar et al. 2012; Mo et al. 2012). Generally, typical factors that have been considered relevant in those analysis are oil prices, the prices of technology stocks, stock market prices, exchange rates, interest rates.

Sadorsky (2001a, 2001b) analyses the expected returns to Canadian oil and gas industry stock prices and finds that exchange rates, crude oil prices and interest rates each have large and significant impacts. Henriques and Sadorsky (2008) deepen the analysis of the relationship between oil prices and aggregate clean energy stock prices and show that rising oil prices are good for the financial performance of alternative energy companies since rising oil prices encourage substitution towards other non-petroleum based energy sources. They underline that this effect is specific of this industry, while normally relationship between oil price movements and stock prices is negative due to the combined effect of two drivers:

[5] For a deep analysis of the theory behind multifactor market models see Elton et al. (2009).

first, rising oil prices increase the production costs of goods and services; this dampen cash flows and reduce stock prices; second, rising oil prices also impact the discount rate used in the equity pricing formula used to value stocks because rising oil prices are often indicative of inflationary pressures, which central banks control by raising interest rates (Aloui et al 2012, Ewing and Thompson 2007, Filis 2010).
Kumar et al. 2012 study the relationship between clean energy stock prices, oil prices, the stock price of technology companies and the carbon market using a vector auto-regression model. They find that carbon price returns are not a significant factor in stock price movements for clean energy; conversely, technology stock prices positively affect the stock prices of clean energy companies since the success or failure of alternative energy companies often depends upon the success or failure of fairly specific technologies; consequently, technology stocks are not a good hedge for clean energy stocks in an optimal portfolio (Sadorsky 2012). It is the case that investors view alternative energy companies as similar to other high technology companies. Mo et al. (2012) also use a multifactor market model to investigate the impacts of European Union Emission Allowance price evolution on the stock performance of European electricity corporations.
We contribute to this field of research with an analysis of the effect of REMs on the clean energy stock prices. Provided that REMs are a production input of primary importance in the green energy industry, and that these materials are at risk of supply disruptions, financial markets could already include these concerns into clean energy companies' valuation.

4 Data and empirical model

We apply the multifactor model using daily observations for the period 2 January 2006 to 24 September 2012. Rare earth material prices are represented by Dysprosium Metal 99% FOB China (named DYM) and Neodymium Metal 99% FOB China (NEOD) and are expressed in U$/kg[6]. The MSCI All Countries Word price index is chosen to measure the equity market performance of developed and emerging markets. It is a free float-adjusted market capitalization weighted index consisting of 45 country indexes. As a benchmark for the oil market and commodity portfolio diversification we use the nearest contract to maturity on the West Texas Intermediate crude oil futures contract (WTI). The interest rate variable is the yield on a 3 months US T Bill (IR3M). Data were collected from Datastream.
For what that concerns Clean Energy Indexes we use time series produced by The New York Stock Exchange – NYSE- and Bloomberg New Energy Finance –BNEF- tracking the world's most active, quoted companies in clean energy. Specifically, the three regional indexes include companies active in the Americas (AMER); Europe, Middle East and Africa (EUAFR); Asia and Oceania (ASOC)[7]. We also consider other indexes representing three subsectors in clean energy: wind, solar and smart technologies (WIND, SOLAR, SMART)[8].

[6] All the empirical studies were carried also with oxide prices obtaining very similar results.
[7] The universe of each index is composed of approximately 2000 companies identified by BNEF as having exposure to clean energy. Companies domiciled in the three areas and listed on non-OTC exchanges with a market capitalization over 1,000MM with a minimum average daily traded volume of 50K share are selected.
[8] WIND index includes companies active in the production of wind turbines, components and subassembly manufacturers, developers, operators, generators, utilities; construction and engineering firms. SOLAR index includes companies active in PV power generation, PV technologies and inputs including feedstocks (polysilicon), ingots, wafers, cells, modules and related components; the production of solar thermal components and technologies; and the development, installation, and operation of PV and solar thermal (STEG) plants. SMART index considers advanced transportation (like electric vehicles), digital energy to improve the efficiency of usage of energy, energy efficiency and storage, fuel cells and hydrogen.

Visual inspection of the data (figure 2) indicates that generally clean energy indexes move with the same trend reaching very high peaks during the end of 2007 and dramatically falling within one year. During 2008-2009 these indexes remain constant or weakly grow until the end of 2010 and drop again during mid-2011. As far as rare material, prices begin to show an increasing trend in the middle of 2009, with a strong soar from beginning 2011. Dysprosium and Neodymium increased until 808% and 436% respectively and after August 2011 prices fall but without reaching the levels before the surge. REMs price increase is mainly due to the above mentioned China cut domestic output and reduced export quotas, while the subsequent price reduction is mainly driven by weak economic growth in the major rare earth consuming nations, slow growth in China, which along with being the world's largest producer of rare earths, is also the largest consumer.

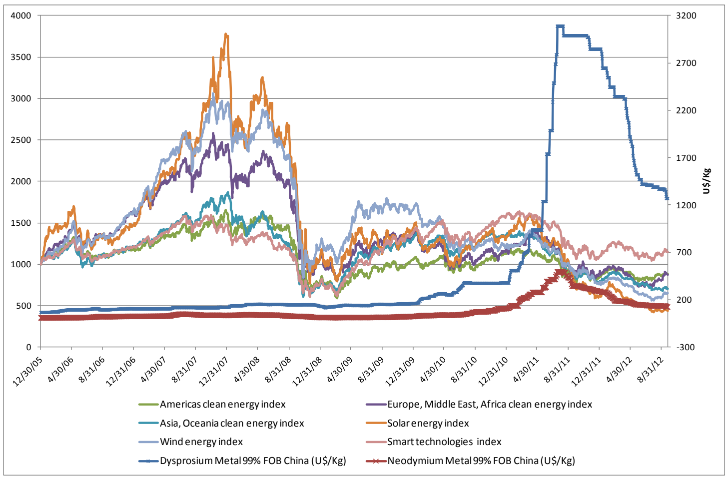

Figure 2. Trend of REM prices (in $/Kg) and clean energy indexes (12/30/2005=1000)
Source: Datastream and Bloomberg New Energy Finance

Figure 3 reports the trend of the other variables used in the model, and shows the dramatic reduction in stock market indices and interest rates in the period just following the bursting of the 2007 financial bubble.

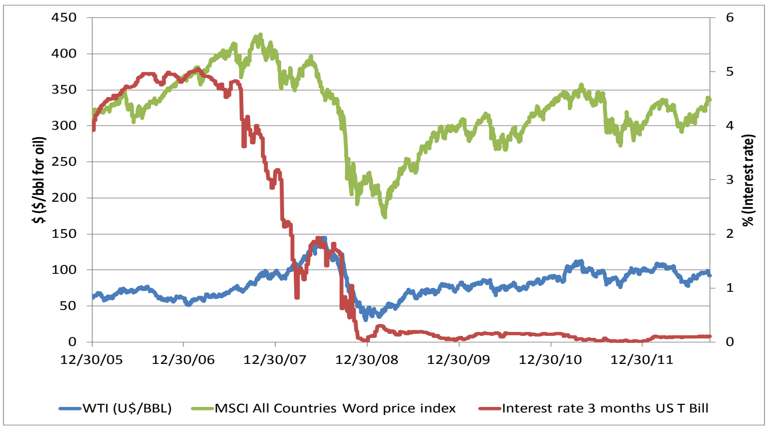

Figure 3. *Trend of Oil price, interest rate and MSCI*
Source: Datastream

Table 2 shows descriptive statistics of continuously compounded daily returns for each series. The t-statistic indicate that the mean is statically significant only for Dysprosium and Neodymium prices whereas others indexes means are statistically insignificant from zero.

Noticeably, the REMs returns display a strong amount of kurtosis and positive skewness so not normally distributed.

Table 2. Descriptive statistics of daily returns

	DYM	NEOM	AMER	EUAFR	ASOC	SOLAR	WIND	SMART	WTI	MSCI
Obs.	1756	1756	1756	1756	1756	1756	1756	1756	1756	1756
Mean	0.165	0.133	-0.007	-0.008	-0.020	-0.046	-0.025	0.008	0.023	0.005
Median	0.000	0.000	0.055	0.122	0.080	0.020	0.059	0.111	0.000	0.094
Std. Dev.	1.568	1.627	1.836	1.976	1.402	2.337	1.721	1.362	2.514	1.256
Kurtosis	188.113	62.251	5.250	6.493	3.379	5.932	10.524	3.262	5.343	6.952
Skewness	10.585	5.117	-0.336	-0.326	-0.771	-0.421	-0.795	-0.329	0.069	-0.403
Minimum	-9.623	-10.279	-11.088	-12.866	-8.132	-12.629	-13.946	-7.435	-12.827	-7.371
Maximum	33.820	24.896	12.224	12.945	5.660	15.192	12.187	7.182	16.414	8.903
t-statistic	4.418	3.434	-0.167	-0.159	-0.592	-0.834	-0.604	0.240	0.386	0.156

*Note: Descriptive statistics are presented for continuously compounded daily returns calculated as 100*ln(pt/pt-1) where pt is daily price.*

For the specific purpose of our study, we specify six multifactor market models where the dependent variables are excess stock returns for clean energy indexes in the three geographical areas and for the three sectors above mentioned. Independent variables are excess stock market returns, oil price changes, dysprosium and neodymium price changes. Excess returns are measured by daily indexes returns minus the three-month US Treasury bill rate. The model is specified as follows:

$$\mathrm{CEI}_{it} = \alpha_{it} + \beta_m \mathrm{MSCIW}_t + \beta_0 \mathrm{WTI}_t + \beta_d \mathrm{DYSM}_t + \beta_n \mathrm{NEOM}_t + e_{it} \qquad (1)$$

with t=1,…..,1756

Where:

CEI are the six excess daily returns on the clean energy stock indexes (ASOC, AMER, EUAFR, WIND, SOLAR, SMART) with i=1,…6; MSCIW is the excess daily return to the market index; WTI is the daily return to oil prices; DYSM is the daily return to Dysprosium price and NEOD the daily return to Neodymium price and e_{it} is the idiosyncratic error. β_0 is the oil beta that is the sensitivity of clean energy stock indexes to oil returns, β_m is the market beta, β_d is the Dysprosium and β_n **i**s the Neodymium beta.

To better estimate multifactor model we first analyze the order of integration of each series by Augmented-Dickey Fuller test (ADF), then we carry out OLS regressions and finally we use a GARCH model to dealing with the presence of heteroskedasticity . Provided that visual inspection of the data indicates two strong breaks during the middle of 2009 and 2011 we also test for the presence of breaks with Chow test (Fisher, 1970).

5 Empirical results and comments

The degree of integration of the variables was tested using the ADF test. Results indicate that all series are stationary[9].

Visual inspections of figures 2 and 3 indicate that strong break occurs in the middle of 2009 and another break is present in the middle of 2011 when REMs prices fall down without reaching past levels. This empirical evidence allows us to conclude that a single regression for all period is not a good fit of the data due to the obvious breaks, so we need to test if these two breaks have occurred in August 2009 and June 2011. Results of Chow test are reported in table 3 and suggest that the two dates are significant in the regressions except

[9] Results are available on request.

for AMER. These results suggest us to proceed estimating two different regressions, one for the whole period and one for the subperiod August 2009-June 2011. This comparison permits us to verify if during this subperiod REM price crisis has influenced the returns of clean energy indexes. OLS results for two periods are reported in table 4 and 5.

Table 3. Chow test results for parameter stability

variable	F-statistic	Prob. F(10,1741)
ASOC	3.104	*0.0006*
AMER	0.379	*0.9559*
EUAFR	1.652	*0.0867*
WIND	4.645	*0.0000*
SOLAR	2.526	*0.0051*
SMART	2.836	*0.0017*

Note: we consider two possible data breaks (08/03/2009 and 06/01/2011) and we calculate F-statistic under the hypothesis that parameters regression are stable over time.

Table 4. Estimates of OLS – entire period

	Dependent variables					
	ASOC	AMER	EUAFR	WIND	SOLAR	SMART
MSCIW	0.999***	1.001***	1.002***	1.001***	1.003***	1.000***
	0.002	*0.002*	*0.002*	*0.002*	*0.003*	*0.001*
WTI	-0.062***	0.047***	0.121***	0.048***	0.113***	-0.009*
	0.011	*0.010*	*0.011*	*0.011*	*0.015*	*0.005*
NEOD	0.003	0.003	0.013	0.006	0.026	-0.003
	0.019	*0.017*	*0.018*	*0.018*	*0.026*	*0.009*
DYSM	-0.021	-0.007	-0.009	-0.003	-0.039	-0.012
	0.020	*0.018*	*0.019*	*0.019*	*0.027*	*0.009*
Intercept	0.000	0.000	0.000	0.000	-0.001	0.000
	0.000	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
Adjusted R^2	0.989	0.992	0.990	0.990	0.981	0.998
ARCH(1)	95.101	177.728	254.389	139.335	61.322	52.441
P-value	0.000	0.000	0.000	0.000	0.000	0.000
ARCH(6)	32.010	60.123	69.990	71.839	35.003	30.791
P-value	0.000	0.000	0.000	0.000	0.000	0.000

*Notes: Values in italic represent standard errors. ***, **, * denote 1%, 5% and 10% level of significance respectively. ARCH(1) and ARCH(6) are Lagrange multiplier (LM) tests for autoregressive conditional heteroskedasticity in the residuals (Engle 1982) at lags 1 and 6.*

Table 5. Estimates OLS – subperiod: August 2009-June 2011

	Dependent variables					
	ASOC	AMER	EUAFR	WIND	SOLAR	SMART
MSCIW	1.003***	0.999***	1.003***	1.003***	1.002***	1.003***
	0.004	*0.004*	*0.004*	*0.004*	*0.005*	*0.002*
WTI	-0.077***	0.067***	0.117***	0.011	0.087***	0.034***
	0.021	*0.017*	*0.018*	*0.018*	*0.026*	*0.011*
NEOD	0.007	0.002	-0.031*	-0.037**	-0.019	0.007
	0.021	*0.018*	*0.018*	*0.019*	*0.026*	*0.012*
DYSM	-0.033	-0.002	0.028	0.034	-0.014	-0.027**
	0.025	*0.021*	*0.022*	*0.023*	*0.031*	*0.014*
Intercept	0.000	0.000	0.000	-0.001***	-0.001	0.000
	0.000	*0.000*	*0.000*	*0.000*	*0.001*	*0.000*
Adjusted R^2	0.992	0.994	0.994	0.993	0.987	0.997
ARCH(1)	1.211	4.529	10.079	41.699	27.156	0.598
P-value	0.272	0.034	0.002	0.000	0.000	0.440
ARCH(6)	32.010	60.123	69.990	71.839	35.003	30.791
P-value	0.000	0.000	0.000	0.000	0.000	0.000

*Notes: Values in italic represent standard errors. ***, **, * denote 1%, 5% and 10% level of significance respectively. ARCH(1) and ARCH(6) are Lagrange multiplier (LM) tests for autoregressive conditional heteroskedasticity in the residuals (Engle 1982) at lags 1 and 6.*

Results of OLS for the entire period show that the adjusted R^2 values are fairly high, indicating a good fit for all the six equations. Results indicate that the estimated coefficients on the market returns are statistically significant, in line with the large literature on the capital asset pricing model (CAPM). Also oil betas are significant even if lower than the coefficients of market. Conversely REMs parameters are not significant indicating that in all the period considered these price changes did not impact clean energy index returns. But if we focus on the period when Dysprosium and Neodymium prices strongly grow, we can see that their coefficients become significant in some cases. However to analyze these results more deeply we have to consider the presence of autoregressive conditional heteroskedasticity in the OLS residuals. ARCH test indicates the presence of ARCH effects in both cases rendering the OLS estimates inefficient.

As an improvement of the results we estimate a generalized autoregressive conditional heteroskedasticity (GARCH) model where heteroskedasticity in the errors is handled properly to obtain more efficient estimators. We use a GARCH(1,1) both for the entire and sub period and we obtain evidence of no ARCH effects (tab. 6 and 7).

Table 6. Results of GARCH estimates: entire period

	Dependent variables					
	ASOC	AMER	EUAFR	WIND	SOLAR	SMART
MSCIW	0.999***	1.000***	1.003***	0.999***	1.001***	1.001***
	0.003	*0.002*	*0.002*	*0.003*	*0.003*	*0.001*
WTI	-0.047***	0.036***	0.101***	0.033***	0.081***	-0.004
	0.010	*0.008*	*0.009*	*0.009*	*0.015*	*0.005*
NEOD	0.004	0.007	-0.022	-0.012*	0.005	-0.001
	0.018	*0.014*	*0.014*	*0.007*	*0.023*	*0.010*
DYSM	-0.018	-0.005	0.014	0.003	-0.014	-0.010
	0.016	*0.018*	*0.011*	*0.011*	*0.022*	*0.009*
Intercept	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
Inter. of var.eq.	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	0.000	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
$resid_{t-1}^2$	0.085***	0.086***	0.099***	0.098***	0.071***	0.064***
	0.015	*0.011*	*0.011*	*0.013*	*0.008*	*0.011*
$garch_{t-1}$	0.891***	0.902***	0.874***	0.867***	0.913***	0.914***
	0.019	*0.012*	*0.014*	*0.018*	*0.010*	*0.014*
Adjusted R^2	0.989	0.992	0.990	0.990	0.981	0.998
ARCH(1)	0.462	1.776	0.045	1.392	5.454	0.189
P-value	0.497	0.183	0.831	0.238	0.020	0.664
ARCH(6)	0.597	0.675	0.740	0.658	1.323	0.453
P-value	0.733	0.670	0.618	0.684	0.243	0.843

*Notes: Values in italic represent standard errors. ***, **, * denote 1%, 5% and 10% level of significance respectively. ARCH(1) and ARCH(6) are Lagrange multiplier (LM) tests for autoregressive conditional heteroskedasticity in the residuals (Engle 1982) at lags 1 and 6.*

Also in this case there are some differences between entire period and subperiod results. The estimate coefficients of market excess returns are positive and significant, as we expected. For all the equations the value of market beta is numerically around 1 providing support for the robustness of results. WTI estimated coefficients are generally higher during the period when prices strongly increased but, interesting, oil prices changes did not affect SMART index return in entire period and WIND index return in the sub-period. Moreover WTI has negative effect on return of ASIA clean index with a coefficient equal to -0.078.

What is most evident is the increasing statistical significance of REMs prices coefficients during the subperiod. In particular EUAFR excess return index seems to be negative affected to changes in Neodymium prices with an estimated coefficient equal to -0.033. Neomydium price changes affect WIND index too with a negative and significant coefficient whereas Dysprosium price changes negatively affects smart industries performances. Conversely, as expected, SOLAR index was not influenced by REMs prices in the two period considered.

Results show that on the overall period under analysis (2006-2012) the clean energy indexes are positively affected by the stock market returns and WTI price changes, in line with the empirical literature on this field of research. REMs price changes generally do not

significantly affect the performance of the three regional and subsector indexes, except for Neodymium in the WIND index equation, where a weak significance is present.
Conversely, during the subperiod when REMs price increase (2009-2011) both Dysprosium and Neodymium do affect the performance of the clean energy stock indexes: Dysprosium and Neodymium price changes negatively statistically affect respectively the performance of SMART and WIND indexes, that make eavy use of those materials, while REMs do not affect SOLAR performances that, conversely, do not make use of those rare elements.
As far as the three regional indexes, the empirical analysis highlights that while REMs do not affect the performance of the ASIA and US clean indexes, Neodymium does negatively affect the performance of the European clean energy index. These results are quite interesting. Indeed, as we already pointed out, Asia is by far the main producer of REMs so we may expect that REMs price increase is not a significant driver of a worsening in the performance of the clean energy sector. The U.S. are less affected by Chinese policies since they are themselves little producers of REMs and are investing heavily in the extraction of REMs. Since stock prices can be viewed as a stream of expected discounted cash flow, the US clean energy index is not affected by REMs price increase since it already discount the benefits of such an industrial national policy. Indeed, the US Department of Energy (DOE) plans to allocate up to $120 million for the creation of a rare earths research facility aimed at decreasing the country's dependence on rare earth elements (REEs) from China.

Table 7. Results of GARCH estimates: subperiod: August 2009-June 2011

	Dependent variable					
	ASOC	AMER	EUAFR	WIND	SOLAR	SMART
MSCIW	1.004***	0.998***	1.002***	1.002***	1.003***	1.003***
	0.006	*0.003*	*0.003*	*0.003*	*0.005*	*0.003*
WTI	-0.078***	0.062***	0.111***	0.020	0.087***	0.043***
	0.020	*0.015*	*0.019*	*0.018*	*0.025*	*0.009*
NEOD	0.010	0.005	-0.033**	-0.031***	-0.017	0.011
	0.025	*0.023*	*0.016*	*0.009*	*0.027*	*0.011*
DYSM	-0.034	-0.002	0.023	0.020	0.000	-0.028*
	0.025	*0.028*	*0.018*	*0.013*	*0.025*	*0.015*
Intercept	0.000	0.000	0.000	-0.001***	0.000	0.000
	0.000	*0.000*	*0.000*	*0.000*	*0.001*	*0.000*
Inter. of var.eq.	0.000	0.000	0.000**	0.000**	0.000**	0.000***
	0.000	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
$resid_{t-1}^2$	0.048*	0.059**	0.080**	0.097***	0.102***	-0.039***
	0.026	*0.027*	*0.031*	*0.028*	*0.026*	*0.010*
$garch_{t-1}$	0.836***	0.898***	0.805***	0.740***	0.571***	1.014***
	0.100	*0.045*	*0.074*	*0.085*	*0.148*	*0.012*
Adjusted R^2	0.991	0.994	0.994	0.993	0.987	0.997
ARCH(1)	0.045	0.379	0.467	0.216	1.883	0.810
P-value	0.833	0.539	0.495	0.642	0.171	0.369
ARCH(6)	0.918	0.243	0.683	0.263	0.890	0.918
P-value	0.482	0.962	0.663	0.954	0.502	0.482

*Notes: Values in italic represent standard errors. ***, **, * denote 1%, 5% and 10% level of significance respectively. ARCH(1) and ARCH(6) are Lagrange multiplier (LM) tests for autoregressive conditional heteroskedasticity in the residuals (Engle 1982) at lags 1 and 6.*

Conversely, the European clean energy stock market index is negatively affected by the price increase of REMs. Specifically, our analysis in a long period of time does not show this effect, but the high volatility of prices linked to the dynamics of production of REMs and extraction problems creates a framework such that the REMs - as happened in the period of strong growth prices under analysis - could again affect stock prices.
In view of the large investments made in support of renewable energy, policy makers need to reflect on the consistency and sustainability of the environmental policies of the EU, which may not take into adequate account the issues of extraction and production of REMs (Moss et al. 2011; Massari and Ruberti 2013).

6 Conclusion

We use a multifactor market model to analyze the impact of Dysprosium and Neodymium price changes to the performance of clean energy industries measured by six clean energy indexes, produced by the New York Stock Exchange and Bloomberg New Energy Finance and tracking the world's most active quoted companies in the clean energy. We consider three regional indexes: 1) Americas, 2) Europe, Middle East and Africa, 3) Asia and Oceania and three subsectors indexes: 1) wind, 2) solar, 3) smart technologies.
Results show that REM prices, in particular Dysprosium and Neodymium - considered more critical materials- influence the performance of WIND and SMART clean green indexes, but only in periods of strong price increase. Among regional indexes, the European clean energy index is negatively affected by an increase in Neodymium prices.
Considering the high level of uncertainty surrounding the sector's supply future and prices, and considering that Europe is putting in place some relevant policy actions in support of clean energy development, the effect of REMs price could weak the aim of the economic and environmental effort in supporting these policies. Indeed, as outlined in the empirical exercise of this paper, a negative relationship between REMs prices and stock prices indexes could influence the maintenances and the development of the sector.
Therefore to reduce the effects of global market force on clean energy sector it is desirable that the EU clean energy strategy involves also a fair co-operation with China. According to Schuler et al. (2011) a possible strategy could valorize the European knowledge and technology in the field of environmental protection (e. g. soil decontamination, landfills, mining areas, groundwater protection etc.) which should be offered to China to reinforce a trade agreement on REMs.

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