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Cost Modelling for Improving Energy Efficiency

PhD Dissertation

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List of Abbreviations

˚C	*Degrees Celsius*
ACC	*Anthropogenic Climate Change*
BEEF	*Bulgarian Energy Efficiency Fund*
CCS	*Carbon Capture and Storage*
$C0_2E$	*Carbon Dioxide Equivalent*
DKEVR	*State Commission for Energy and Water Regulation*
EC	*European Commission*
EEAP	*Energy Efficiency Action Plan*
EEP	*Energy Efficiency Plan*
EPBD	*Energy Performance of Buildings Directive*
ESCO	*Energy Service Company*
EU	*European Union*
EUR	*Euro*
GDP	*Gross Domestic Product*
GHG	*Greenhouse Gas Emissions*
Gt	*Gigaton*
IPCC	*Intergovernmental Panel on Climate Change*
KGOE	*Kilogram(s) of Oil Equivalent*
KTOE	*Kilotons of Oil Equivalent*
kWh	*Kilowatt Hour*
M€05	*Millions of Euros in their 2005 Value*
MEET	*Ministry of Economy, Energy and Tourism*
MTOE	*One Million Tons of Oil Equivalent*
MTOE	*Megatons of Oil Equivalent*
MTON	*One Million Tons*
NAPs	*National Action Plans*
NREAP	*National Renewable Energy Action Plan*
OP	*Operational Programme*
R&D	*Research and Development*
REECL	*Residential Energy Efficiency Credit Line*
RES	*Renewable Energy Sources*
SDS	*Sustainable Development Strategy*
SEE	*South East Europe*
SPSS	*Statistical Package for the Social Sciences*
TOE	*Tons of Oil Equivalent*
TOE	*Tons of Oil Equivalent*
UN	*United Nations*
UNDP	*United Nations Development Program*
USD	*US Dollars*
VAT	*Value Added Tax*
WSSD	*World Summit on Sustainable Development*

Introduction

As of 2013, Bulgaria has the most energy intense economy of the twenty-eight member states of the European Union, as well as very high relative levels of relative energy poverty. A McKinsey study from 2009 entitled *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve* indicates that many energy efficiency improvements can be undertaken at negative cost. That is to say, implementing any of these interventions has net economic and environmental benefits. This is an intriguing finding in that much rhetoric about abating carbon focuses on the proposition that attempts to address greenhouse gas emissions are usually harmful to economies due to the additional costs that such actions may impose on businesses. Also, these possibilities may be somewhat troublesome for believers in the allocative efficiency of markets, in that such opportunities would be captured by these markets if such strong allocative efficiency in markets existed. While this may be somewhat of a "straw man" argument in that presumably, the vast majority of economists and thinkers understand the limitations of this assumption due to informational, behavioural and other dynamics, the potential to unlock these simultaneous economic and environmental benefits should be attractive to environmentalists, economists, energy service companies, and policy-makers alike.

However, this investigation does not aim to explore why such negative or low-cost opportunities might not be captured, but rather, if they do exist, to what extent they could be beneficial in the Bulgarian context. Various carbon cost abatement models have been deployed within this study to help better understand the costs involved in various levels of emissions cutbacks from a baseline scenario. To that end, the emissions baseline scenario in Bulgaria was studied. Additionally, the costs and potential benefits for basic residential building envelope refurbishment in the country were calculated. Additionally, the degree to which greenhouse gas emissions in Bulgaria can be adequately promoted, given existing financial outlays, was also considered.

It was found that while there may indeed be some basic building envelope refurbishments that have negative or low costs over their life-cycle, the depth at which these refurbishments are often undertaken in individual buildings may go beyond cost optimality. It is inferred from this study that low-tech energy efficiency improvements in residential buildings over a greater number of buildings, or a combination of basic energy efficiency improvements in buildings, combined with energy efficiency interventions in other sectors, may result in a more optimized expenditure of public money from an energy savings and emissions perspective. Based on these findings, some possibilities for public policies in this area have been considered.

Subject and Object of the Research

In this paper we studied the possible environmental (in terms of greenhouse gasses abated) of basic building envelope refurbishment in residential buildings in Bulgaria. We also investigated theoretically possible levels of carbon abatement with the existing financial outlays that are earmarked for this task through the use of carbon abatement models. These potential levels of carbon abatement were compared with the emissions targets for Bulgaria in 2020 to gain insight into their feasibility.

Main Purpose and the Research Tasks

The main purpose of this study is to determine the costs involved in reducing greenhouse gas emissions in Bulgaria through basic envelope refurbishments in residential buildings, and to determine the level of emissions that could theoretically be abated using existing available financial outlays extrapolated to 2020. In order to achieve this, the following research tasks were undertaken:

- Forecasting greenhouse gas emissions for each year between 2015 and 2020 – this was constructed through the use of historical data and forecasted data sets for population growth, growth of GDP per capita, changes in the energy efficiency of the economy, as well as the carbon efficiency of energy;
- Calculating the GDP needed to achieve different abatement cutback levels using the three cost models;
- Calculating the level of possible greenhouse gas emissions abatement, and the abatement costs, for basic building envelope retrofits;
- Calculating building envelope abatement costs using real cases and comparing these to the theoretical models;
- Determining current financial outlays for energy efficiency measures in residential buildings in Bulgaria and determining theoretically possible level of emissions abatement using this financing;
- Gaining insights into public opinion regarding their views on sustainable consumption and potential green taxes.

Hypothesis

As a result of the age and inefficiency of the majority of the residential building stock in Bulgaria, and the relatively low labour costs in the country, it was anticipated that the costs and benefits for residential building envelope retrofits would have potential economic benefits in line with those in the McKinsey report. It was also hypothesized that existing financial outlays for improving energy efficiency in the country would not be enough to meet stated emissions reductions targets considering that the energy intensity of the economy continues to be unaddressed.

Methodology

Methodologies used in the examination of the hypothesis included:

- Emissions forecasting analyses based on data from the U.S. Census Bureau, Eurostat, the International Monetary Fund, the Bulgarian Statistical Institute and the European Environmental Agency;
- Three existing theoretical emissions reduction models adapted and deployed to the Bulgarian context;
- Expert interviews with the Sofia Energy Agency regarding the experienced benefits of building envelope retrofits (SOFENA);
- Desk research into available financial instruments and financial outlays for energy efficiency in Bulgaria and in calculating emissions and energy reduction targets in Bulgaria from various policy documents;
- Survey analyses of the Parliaments and Civil Society in Technology Assessment (PACITA) project.

There are a number of limitations in this study. Firstly, in calculating the projected emissions levels in Bulgaria between 2015 and 2020, a number of data sets were used which themselves have built-in assumptions that may or may not prove to be true or be accurate. The growth rate of the Bulgarian population, the growth rate of GDP per capita, the output per unit of energy, and the carbon efficiency of energy all have varying degrees of uncertainty. The rate at which the Bulgarian population will change over time is the least uncertain of all of these projections as evidenced by the relatively small differences in the Upper (UCL) and Lower Control Limits (LCL) as compared to the other projections. Conversely, the most uncertain of these projections is that for the carbon efficiency of energy, where the UCLs and LCLs diverge drastically starting in 2015 due to the lack of definite trends in the historical data set used for the projection until 2020.

Secondly, for the three cost models that were deployed, major assumptions had to be made as to which cost parameters to use in each model. In the case of the CRED-Two Parameter Model (and in the other two models as well), no parameters for Bulgaria were available. Therefore, a group of countries with presumably similar economic histories and development levels to Bulgaria were selected. It was decided that of the available options, that those from Kazakhstan, Russia and Ukraine could be used – particularly because of their geographic proximity to Bulgaria and because they all had the exact same calculated parameters. This also had to be done when using the RICE model, where values for the European Union as a whole were used as a proxy for Bulgaria, despite probable divergence of costs and existing efficiency levels across the EU. Finally, when deploying the EMF-22 Model, the parameters for the Annex 1 Parties to the United Nations Framework Convention on Climate Change were used, of which Bulgaria is included. While these proxy parameters may introduce some error into the cost calculations, this is an inherent problem in applying data from top-down macroeconomic cost models to smaller units of analysis.

Thirdly, when calculating the cost of the McKinsey basic renovation package according to each cost model, it was assumed that the McKinsey analysis accurately included every possible carbon abatement intervention and did so in the correct order according to cost. When using the cost models to calculate the cost of this particular intervention, each intervention was, in a sense, overlaid on each cost model, so that the costs where that particular basic residential envelope refurbishment laid on the cost model curve could be calculated. If the McKinsey model did not include a particular intervention, or miscalculated the costs of a particular intervention, then these calculations will be incorrect.

Fourthly, when trying to locate real case-based data in order to gain insights into the costs and benefits of energy efficiency interventions, there were limitations on the number of cases where raw data could be found. Since such data was only located for three buildings, there could be major discrepancies between these buildings and the costs and benefits for similar interventions on a national, regional, or even city-wide scale. While we were apprehensive about generalizing from such a small number of cases, we felt that it could be useful in order to gain insights into what benefits such interventions could deliver to society if all earmarked funds were spent on this particular intervention. Also, the interventions undertaken in the STACCATO project were slightly more thorough in scope than those proposed by the refurbishment package from McKinsey that was investigated within this study. As such, a one-to-one comparison of these two interventions could not be conducted and inferences into the differences and similarities between them had to be made in order to make an attempt to draw conclusions from them.

Fifth, it is only possible to roughly approximate the financial outlays that are available for energy efficiency improvements in Bulgaria. The plethora of programs and funds that were identified for such measures all have different priorities, procedures, administrative overheads and timelines that make highly accurate estimations impossible. It is important to note this in understanding that the potential cutbacks from the baseline scenario that were estimated, could be significantly different depending on the degree of error in these estimations as well as how financing trends will develop in the future.

Sixth, and finally, there are some issues with the data from the survey conducted within the PACITA project in that it was not necessarily representative of Bulgarian society and/or the viewpoints held by Bulgarian citizens and those from the other European countries included within it. Thus, there could potentially be issues in using this data to support the conclusion that Bulgarian citizens (and many European citizens) might not want to consume less, regardless of the reason, as well as to support the view that the majority of Bulgarians do not want to change income based taxation to taxation on consumption.

I. The Case for Limiting Greenhouse Gases through Energy Efficiency Measures

The earth is warming, and the consensus among experts that it is being caused by humans is nearly unanimous.[1,2] The *Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC) notes that "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century."[3] In the report, the term "extremely likely" is used when a phenomena has a 95-100% probability of being true. Thus, the debate as to whether or not the majority of observed global warming during the latter half of the 20th and beginning of the 21st centuries is caused by human activities is effectively a manufactured one, with both political ideology and economic interests muddying the waters of scientific evidence in the public sphere.[4] As with all scientific findings, there is no statement made or implied in such climate research as to the absolute certainty of the findings. While the data, as interpreted by climate experts, overwhelming supports the theory that the vast majority of the observed warming results from human activities, scientific, and indeed rational thinking dictates that other possible explanations may exist. The complexity of the global climactic system and the inherent difficulties in disentangling causes and effects within such a system is extremely challenging – but does not preclude sound evidenced-based conclusions from being made.

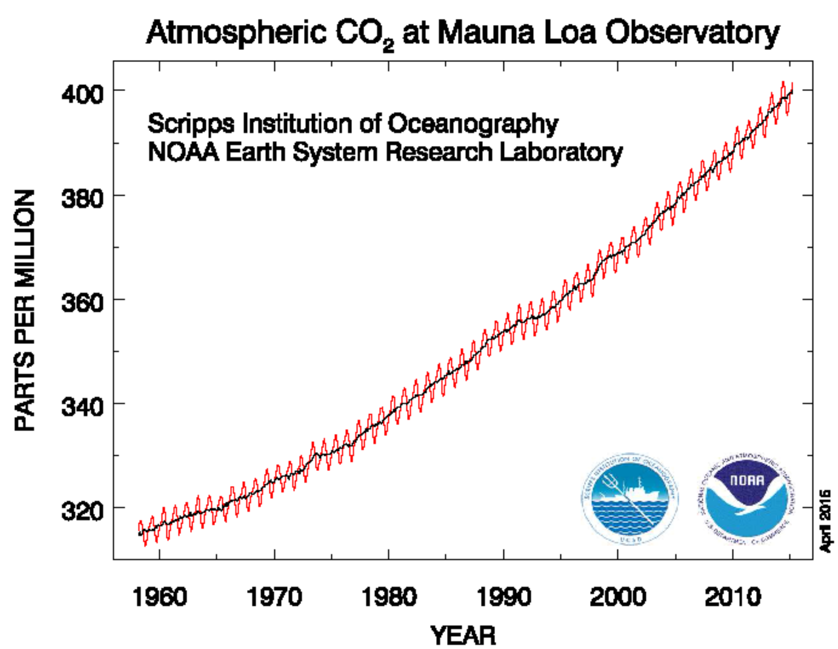
In addition to criticisms of climate science that focus on mischaracterizing the meaning of such small margins of uncertainty amongst the public, there is another small cohort of climate deniers, some with notable academic credentials, who have emphasized the positive effects that global warming may have on the planet.[5] These benefits, they claim, include the possibility that increased $C0_2$ concentrations could accelerate photosynthetic processes, extend growing seasons, and perhaps result in a reduced need for heating-related energy expenditure and resource usage. These possibilities do illuminate the reality that there could be some silver lining in the upward climb of global temperatures and in changes to the chemical

[1] **Intergovernmental Panel on Climate Change**, *Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis*, 2013.
[2] **Doran, Peter T., Maggie Kendall Zimmerman**. *Examining the Scientific Consensus on Climate Change*, Eos, Transactions American Geophysical Union, Volume 90, Issue 3, pages 22–23, 20 January 2009.
[3] **Intergovernmental Panel on Climate Change**, *Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis*, 2013.
[4] **Oreskes, Naomi. Conway, Erik M.,** *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming*. Bloomsbury Press, New York, U.S.A., 2011.
[5] **Singer, S. Fred**, *Benefits of Global Warming*, Society, March-April 1992, Volume 29, Issue 3, pp 33-40.

composition of the atmosphere. However, while not necessarily untrue in narrowly-defined contexts, these views cherry-pick potential realities of a possible future, while ignoring other systemic negative externalities.

Rises in temperature beyond the 2°C threshold (the level below which a broad scientific consensus believes the most serious effects of global warming can be avoided) agreed upon by G8 leaders in 2009, now seem imminent. The IPCC Fifth Assessment Report has indicated that temperatures could rise by up to 4.8°C by 2100.[6] According to the *Report of the Steering Committee of the International Symposium on the Stabilisation of Greenhouse Gases* in 2005, limiting global warming to 2°C "with relatively high certainty" would require CO_2 concentrations to stay below 400 parts per million (ppm).[7] In March 2015, these concentrations were 401.52 ppm (see Figure 1).

Figure 1 – Atmospheric CO_2 at Mauna Loa Observatory



Source: Scripps Institution of Oceanography and NOAA Earth System Research Laboratory

[6] **Intergovernmental Panel on Climate Change**, *Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis*, 2013.
[7] **International Symposium on the Stabilisation of greenhouse gas concentrations** - Report of the International Scientific Steering Committee" (PDF). Met Office. May, 2005. <http://www.g8.utoronto.ca/environment/2005steeringcommittee.pdf>.

The negative effects from such rises is likely to include disruptions in agricultural production, negative effects on human health, ocean acidification, sea-level rise (affecting coastal human settlements), reductions in biodiversity and potential species extinctions, and new patterns of extreme weather events. These all have the potential to cause massive negative economic harm that far exceeds the costs of early, or even late, mitigation efforts. There are some estimates that calculate that delays in action that results in 3°C could increase economic harm by .9% of yearly global output.[8]

Many critics of the anthropogenic global warming consensus attack this well-evidenced theory based on economic and ideological grounds rather than scientific ones. They are often spring-boarded by institutions which fiercely guard free-market principles, and are proponents of small government and obdurately uphold uncompromising ideas of personal freedom.[9] At the most extreme end of the spectrum, anthropogenic climate change (ACC), is purported to be a hoax perpetuated by one or more of a plethora of actors looking to covertly redesign economic systems, secure scientific grant money, or curb constitutionally protected rights and freedoms. Some more moderately minded climate change deniers view its potential harm as overblown and that any negative effects can be addressed through adaptation efforts and technological advances.

One facet in this line of reasoning is the idea that addressing the degradation of the Earth's air, water and land resources will unleash an unbearable GDP slowdown on countries that attempt to do so. At the heart of the present investigation is an attempt to show that this assumption is patently false. While probing the depths of the human psyche is not within the scope of this paper, we speculate that such thinking finds its roots in the human desire to achieve certainty and to mentally migrate to simplified and easily understood positions, especially in the political sphere. On the contrary, much economic research points towards the need to address these negative externalities so as to ensure the sustained availability of economic throughputs and to avoid economic cannibalization of the Earth's natural capital. A rhetorical, albeit overly simplistic counter-factual can be levelled at arguments in this vein: *on a finite planet, how can unabated climate change and the unsustainable consumption of natural resources not harm economic progress in the long-term?*

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[8] The Cost of Delaying Action to Stem Climate Change, Executive office of the President of the United States, July 2013. Retrieved from http://www.whitehouse.gov/sites/default/files/docs/the_cost_of_delaying_action_to_stem_climate_change.pdf

[9] **Dunlap, Riley E. and Jacques, Peter J**, *Climate Change Denial Books and Conservative Think Tanks: Exploring the Connection, American Behavioral Scientist, June 2013 57: 699-731*

In an effort to avoid making straw-man arguments, it should be said that the concerns about economic damage resulting from badly designed regulation are legitimate and should not be ignored. However, jumping from here, to the conclusion that environmental regulation and unfettered economic activity should be avoided because of this possibility, does not follow. Rather, it puts the onus on policy-makers to find solutions which achieve economic, environmental and social objectives in parallel, rather than to view policy-making as a zero-sum game of trade-offs. Indeed, the existence of ACC does impose an imperative on humanity to change its patterns of open-looped consumption and does not inherently imply a reduction in living standards. If the benefits of the free-market are to continue to spread geographically and over time, it is necessary to redirect modes of economic exchange towards a paradigm that can be sustained indefinitely.

In the face of various real-world constraints: financial, political, social and technological, it is vital to develop a strategy that has a chance of successfully navigating them. One approach in penetrating resistance in addressing climate change stems from a very simple idea - yet one that finds its realisation quite difficult – the reduction of energy waste. Wasted resources almost never contribute any direct value to society, except perhaps monetarily through the perverse incentive system which may make them more financially beneficial through increases in their scarcity and use. While the climate change challenge cannot be solved by reducing energy waste alone, the challenge is so large, so systemic, that it cannot be tackled without it. Fascinatingly, investigations into many energy efficiency improvements has shown that many forms of energy waste can be addressed at low or even negative costs. A McKinsey study from 2008 highlights that "depending on how new low-carbon infrastructure is financed, the transition to a low-carbon economy may increase GDP growth in many countries".[10] In the case of the U.S., for example, a report found that[11]

> **Almost 40 percent of abatement could be achieved at "negative**" marginal costs, meaning that investing in these options would generate positive economic returns over their lifecycle.

Taking this finding, together with the high recorded levels of energy poverty and air pollution in Bulgaria, a solution that can simultaneously help address poverty, improve human health and reduce global environmental harm is considered. While

[10] **McKinsey Global Institute**, *The Carbon Productivity Challenge: Curbing Climate Change and Sustaining Economic Growth,* June, 2008.
[11] **McKinsey & Company**, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?* December, 2007.

the health and social benefits are not explicitly calculated herein, the economic costs of implementing such measures are.

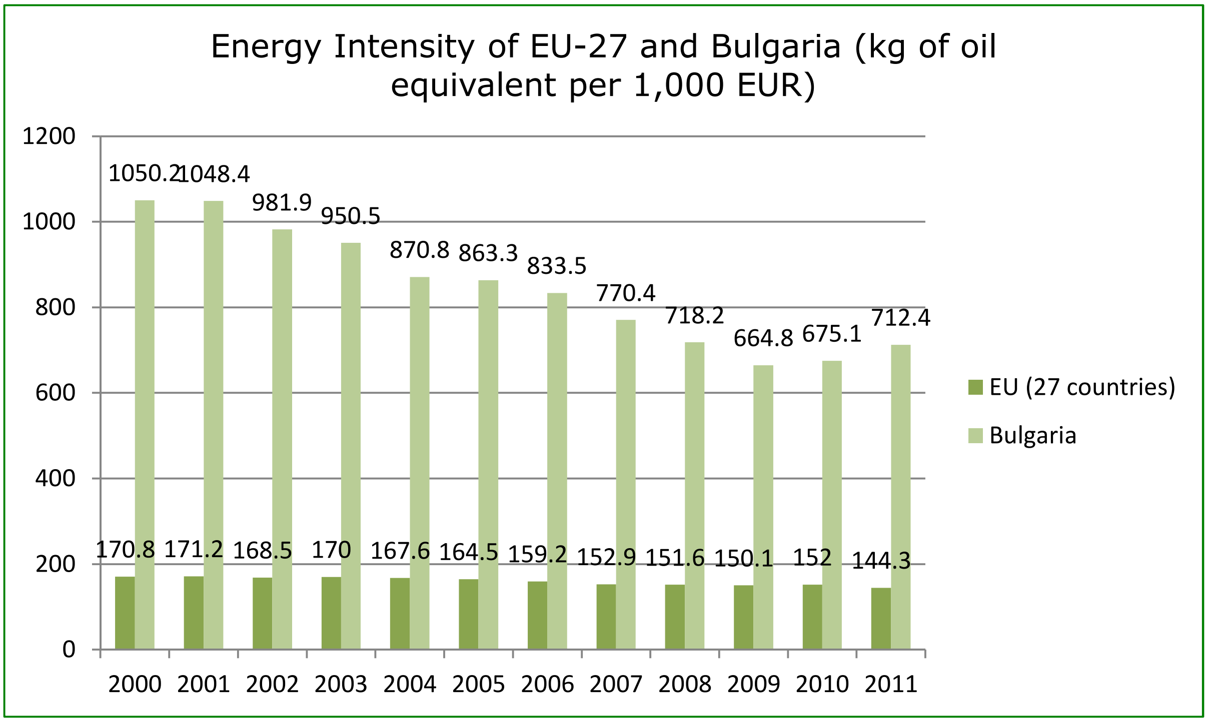
1. Bulgarian Energy Efficiency Dynamics

In many parts of Eastern Europe, including Bulgaria, energy continues to be subsidised by the state.[12] This circumvention of market mechanisms, which undervalue the price of energy, is harmful to the efficient use of energy resources. While politically expedient, such distortions harm market-based incentives for the use of more efficient energy sources and in improving energy efficiency.[13] The assumption that artificially reducing the cost of energy will be an overall benefit to society is myopic in that it may be very harmful to the future economic prospects of countries and their energy security.

Such distortions can also create problems when trying to develop EU-wide policy measures to address climate challenges, and in meeting EU energy and environmental goals. According to Eurostat data, in the first half of 2013, the price of electricity in the EU for domestic consumers was the highest in Denmark, with .3€/kWh, and was the lowest in Bulgaria, at .0924 €/kWh. The price in Denmark consisted 56.6% of taxes and Value Added Tax (VAT) whereas in Bulgaria only VAT was applied, resulting in 16.5% of the final price being composed of the VAT tax.[14] Such disparity in pricing, resulting from taxation and subsidisation schemes, can make policies which aim to utilize taxation to improve the environmental performance of the energy system quite difficult to engineer across the entire European Union. While other factors are also important, in such a context of relatively cheap energy and outdated infrastructure, it is not wholly surprising that Bulgaria is the most energy intense economy in the EU, while Denmark is the second most energy efficient, only behind Ireland. This energy intensity in Bulgaria has also increased between 2009 and 2011, in contrast to the EU-27 as a whole (see Figure 2).

[12] **IEA, OPEC, OECD, The World Bank**, *Analysis of the Scope of Energy Subsidies and Suggestions for the G-20 Initiative*, June, 2010.
[13] **Center for the Study of Democracy**, *Bulgaria's Energy Security Risk Index, Policy Brief No. 40,* September 2013.
[14] **Eurostat Energy Price Statistics**, *Electricity Prices for Domestic Consumers, from 2007 Onwards - Bi-Annual Data*, Retrieved on November 7th, 2013.

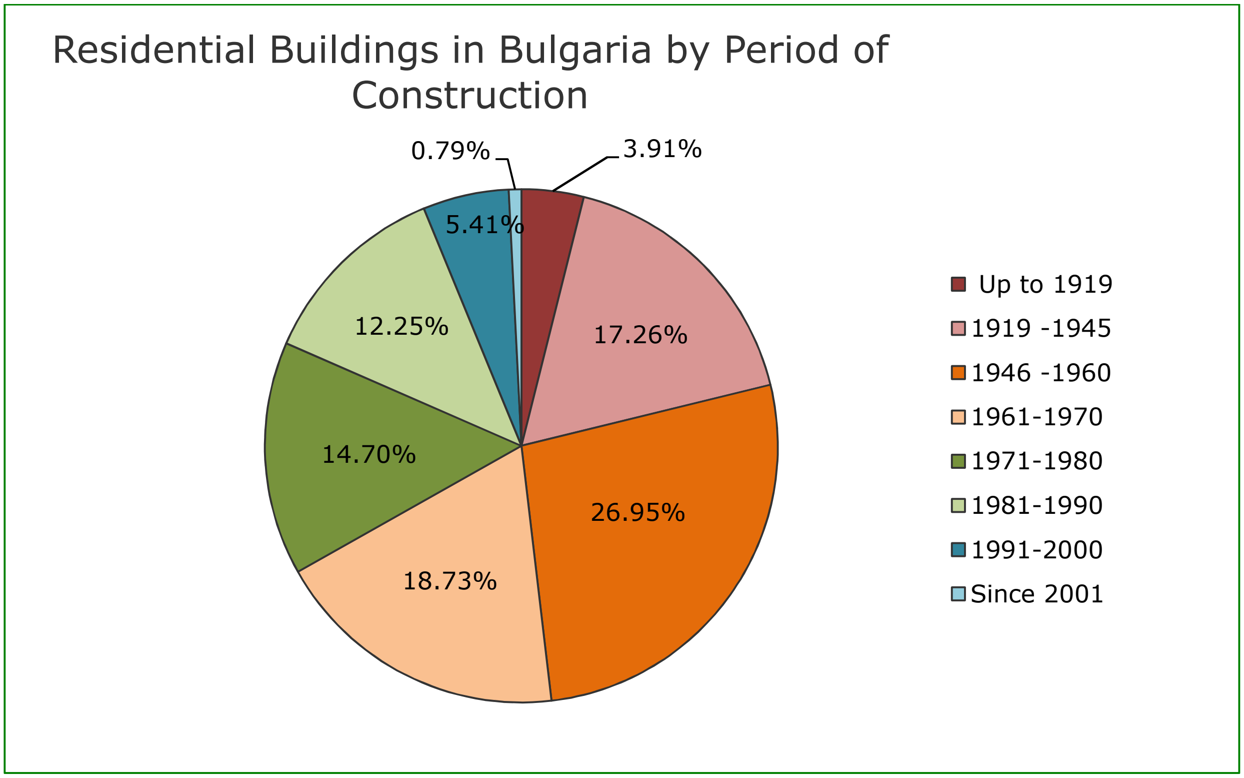
Figure 2 - Energy Intensity of EU-27 and Bulgaria



Source: Eurostat Data, Energy Intensity of the Economy (tsdec360) and Own Calculations

While discussions about taxation "wake the dragon" about the role of government in markets, energy efficiency measures can circumvent some of the controversial aspects of the taxation debate for consumers and voters, since direct savings to end-users are more visible. More specifically, the housing sector is a suitable area of intervention in Bulgaria given the dynamics of the built environment. Data for Bulgaria, from 2009, reveals that 93.8% of residential housing in Bulgaria was built before 1990 (see Figure 3).

Figure 3 - Residential Buildings in Bulgaria by Period of Construction



Source: National Statistical Institute, Housing Fund, and Own Calculations 2009

Thermal insulation standards in Bulgaria date back to the 1960's, although efficiency regulations were not introduced until 1992 (and subsequently updated in 1999 and 2004) and serious consideration of insulation was not considered until the mid-1980s.[15] This has led to a situation where many buildings in Bulgaria have insufficient, or no, thermal insulation.[16] Data from the 2011 Census in Bulgaria showed that only 15.5% of households in Bulgaria have outside thermal insulation, while only 29% have low-energy windows or doors.[17] Addressing this large opportunity in the Bulgarian economy, by reducing end-user costs for heating and cooling improvements, improving thermal comfort, and reducing emissions levels, can be addressed simultaneously if the current incentive structure for implementing such measures is redesigned. Energy efficiency improvements in this area, rather than requiring economic sacrifice, can supplement the underpinnings of a new wave of economic development founded on the principles of sustainable consumption.

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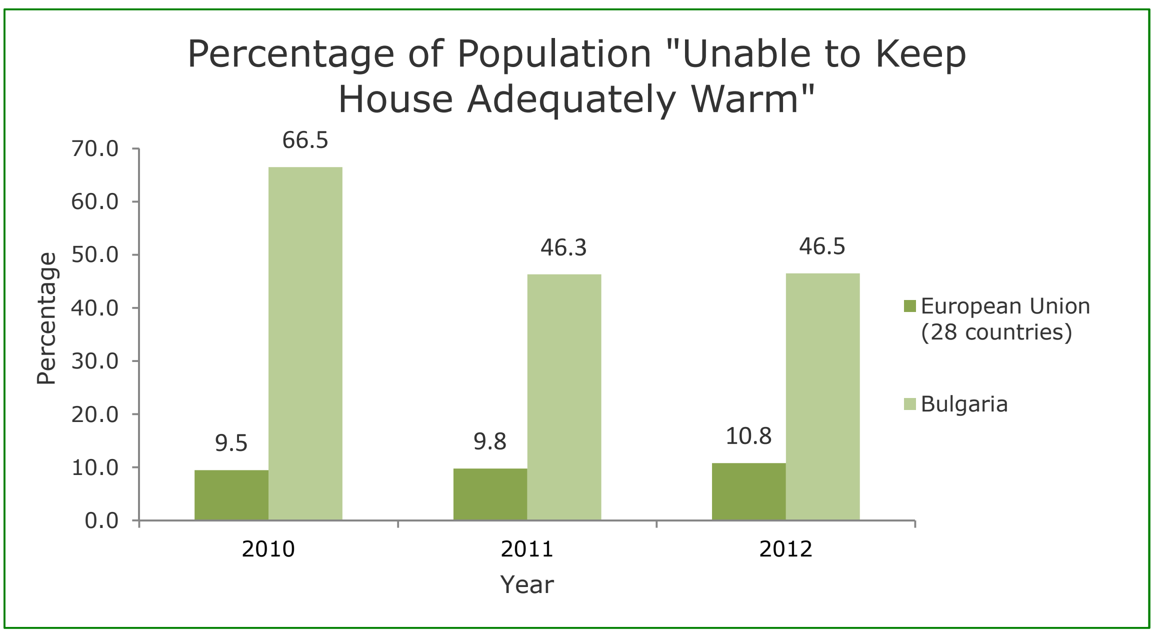
[15] **Ilieva, Lucia**. *Housing in Bulgaria: Challenges and Perspectives,* OSI Europe Foundation, LGI – Housing the Poor, 2003.
[16] **Folić, Radomir, Mirjana Laban and Verica Milanko,** *Reliability and Sustainability Analysis of Large Panel Residential Buildings in Sofia, Skopje and Novi Sad.* Architecture and Civil Engineering Vol. 9 No. 1, 2011.
[17] *2011 Population Census*, National Statistical Institute, Republic of Bulgaria. Retrieved on August 31st, 2014 from http://www.nsi.bg/census2011/PDOCS2/Census2011final_en.pdf.

Bulgaria's high energy intensity is an artefact of a number of elements, including infrastructure for industry and housing which was developed under a system of heavily subsidised energy, the need for rapid development, and a lack of civil society which might have injected environmental concerns into public discourses. In fairness, the figure is also affected by Bulgaria's low gross domestic product, which elevates the importance of non-productive fixed energy expenditures, such as those for heating, energy production and transmission. Also, as previously mentioned, the circumvention of market mechanisms was the *de facto* philosophy of the era, which prevented the efficient allocation of energy and energy efficiency improvements which make more financial sense in an environment with clear market signals. However, as will be shown, the power of markets to efficiently allocate resources and capture value also has limitations.

As a result of this relatively high starting point for energy intensity, there is significant potential to reduce it. According to the *National Reform Programme of Bulgaria*, updated in 2014, Bulgaria has committed itself to improve energy efficiency by 25% by 2020, compared to a baseline scenario.[18] Energy efficiency in buildings can aid in the achievement of this target while addressing energy poverty, as thermal comfort not affordable for many households in the country (see Figure 4).[19]

Figure 4 - Energy Poverty in Bulgaria

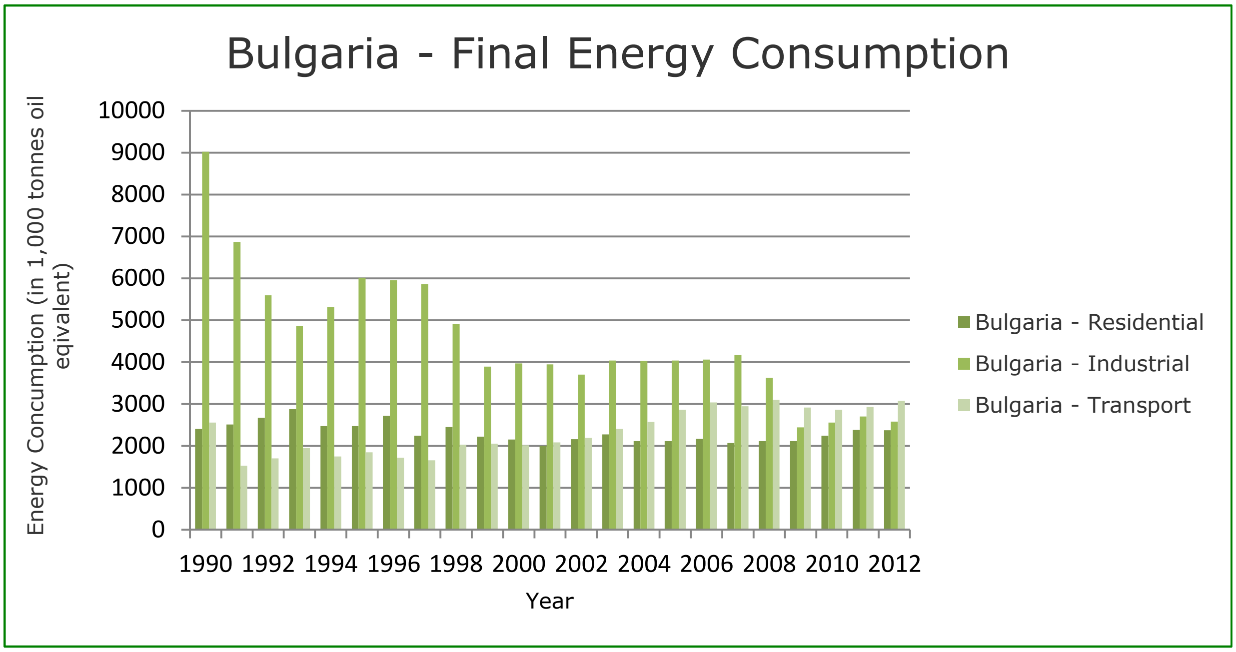


Source: European Union Statistics on Income and Living Conditions

[18] *Europe 2020: National Reform Programme of Bulgaria: 2014 Update,* Ministry of Finance, Republic of Bulgaria. Retrieved on August 31st, 2014 from: ec.europa.eu/europe2020/pdf/csr2014/nrp2014_bulgaria_en.pdf
[19] **Eurostat Data**, *GDP per capita in PPS* (tec00114). Retrieved on January 9th, 2013.

In 2012, the transport sector consumed 33.31% of final energy, industry consumed 27.95%, and the residential sector consumed 25.7%.[20] As can be seen in Figure 5, over the past 25 years, energy consumption in industry has collapsed. Energy consumption in the residential sector in Bulgaria is characterized by the consumption of low efficiency renewable energies (i.e. firewood) and electricity as well as by the more efficient derived heat in the form of central heating. According to National Statistical Institute data from 2013, in Bulgaria, 34.1% of all households used wood as a main heating source, 28.6% used electricity, 19.81% used coal, 16.37% used central heating, and .68% used gas.[21] This mix is driven both by the price point of each heat input and the costs of equipment needed to transform it into heat, with wood (62.8%) and coal (32.4%) constituting most energy consumption in the form of heat in rural areas and contributes to poor air qualities. Electricity was the largest heating source in urban areas (38.26%).[22] Bulgarian households are particularly sensitive to energy costs given that the average yearly Bulgarian household income was €6,188 in 2013.[23]

Figure 5 - Final Energy Consumption by Sector in Bulgaria



Source: Eurostat Data, Final energy consumption by sector (tsdpc320) and own calculations.

[20] **Eurostat Data**, *Final energy consumption by sector* (tsdpc320) and own calculations. Retrieved on September 1st, 2014

[21] **Center for the Study of Democracy**, Energy Saving Technologies in the Bulgarian Residential Sector.

[22] Holliday, Zoe, Galev, Todor, Nadejda Gantchenva, Center for the Study of Democracy: Energy Security in Bulgaria – Policy Tracker: Key Challenges for Energy Efficiency Policies in the Domestic Sector, 2014.

[23] **Bulgarian National Statistical Institute**, Household Income and Expenditure – Annual Data – Retrieved from http://www.nsi.bg/en/content/5640/households-income-and-expenditure

In general, while energy efficiency improvements in buildings with negative or low abatement costs will not meet energy and climate objectives by themselves, they are the "low-hanging fruit" in the energy system at present. A literature review has revealed that the marginal cost of improving energy efficiency in buildings is lower, per ton of CO_2 abated, for initial improvements than through other approaches, such as renewable energy and CCS.[24]

While theoretically, any efficiency improvement which has a negative (or zero) abatement cost during its life-cycle would be captured by the market, in reality, a number of challenges to their deployment exists. These include the principal-agent problem, a lack of information about potential cost-savings, a lack of up-front capital, uncertainty about future energy prices, and rationally uninformed perceptions about the benefits of small efficiency improvements.

As such, financial instruments which promote the availability of capital for efficiency improvements, and financial instruments to promote energy efficiency, are needed to help overcome such issues and to uncork the value currently untapped in energy efficiency. With such low levels of disposable income to use on efficiency improvements amongst consumers in the country, a poverty trap is created and exacerbated by poor living and air quality, and relatively high energy and heating costs. The following investigation aims to reveal the potential GHG emissions that can be prevented through basic building envelope refurbishments in residential buildings in Bulgaria, the cost for doing so, as well as the total potential emissions that could be abated in Bulgaria considering currently available financial outlays.

[24] **McKinsey & Company (2009)**. *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*. Retrieved on Aug 19th, 2012 from: http://globalghgcostcurve.bymckinsey.com

2. Energy Policy in the European Union and Bulgaria

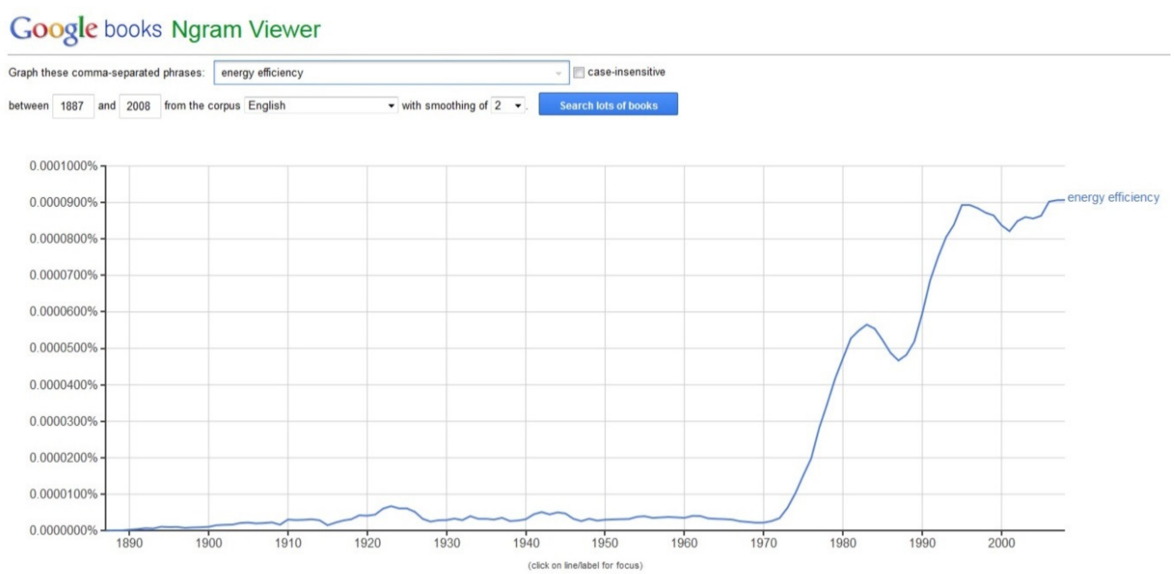
2.1 EU Energy Efficiency Policy

While energy efficiency is not defined in the European Treaties, a definition is given in a Directive of the European Parliament and of the Council from 2012: [25]

> *'energy efficiency' means the ratio of output of performance, service, goods or energy, to input of energy;*

Without a doubt, the term 'energy efficiency' has been used with different definitions, or without specifically defining it, throughout time and place. The definition above, no doubt, is somewhat close to what most of those using the term perceive it to be – namely to provide the same, or greater, levels of energy-services with the same or less amount of inputs to deliver them. Figure 6 below shows the frequency of the term between 1887 and 2008 in the Google Ngram Database. The year 1887 was chosen as a start year since no usage of the phrase 'energy efficiency' were noted is this database as occurring before that year.

Figure 6 - Frequency of Term 'energy efficiency' in Publications Available in Google's Ngram Viewer Database[26]



[25] **DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012** - on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

[26] This shows the percentage of books in the 5.2 million digitized books in Google database where the phrase 'energy efficiency' was written.

Source: Extracted from Google Ngram Viewer

While the concept of energy efficiency seems to have been used prior to the early 1970's, popular usage of the term drastically increased around that time. It was in 1973, when, according to Donald R. Wulfinghoff, the "modern era" of energy conservation began.[27] This was when an embargo on the export of oil to the United States, resulting from a reaction of major oil-exporting states to U.S. policy in the Middle East, was imposed. As a result, energy prices rose due to the imposed shortages and "the realization that energy sources might not keep pace with mankind's ability to use energy" emerged. [28] It was also around this time when the research of environmental scientists and academics broke onto mainstream consciousness with books like *The Population Bomb* (1968) and *The Limits to Growth* (1972), which explored the impacts of humanity on the earth and environmental limits on economic growth.

More recent works, such as *Natural Capitalism* (1999) by Paul Hawken, Amory Lovins and L. Hunter Lovins, focus on the idea that inefficient patterns of consumption, coupled with population growth, are the main causes of the destruction of natural capital and that significant increases in resource productivity are needed in order to direct economic systems towards a new sustainable paradigm. There is a particularly relevant conceptualisation of energy efficiency that is presented in that work, regarding the knock-on effect that downstream energy savings can systemically leverage upstream, up to the point of production. Given that the conversion, transmission and storage of energy all result in energy losses, saving one unit of energy at the end-user stage can save orders of magnitude more energy than just that viewing the amount of energy saved at its consumption point.[29]

The European Union is among the world leaders (and is by most measures the world leader) in the creation of strong environmental public policies. Through its Europe 20-20-20 strategy, officially known as the *European Union Climate and Energy Package*, it aims to reduce greenhouse gas emissions by 20% compared to 1990 levels, increase renewable energy to 20% of the energy mix, and reduce energy consumption by 20% against a baseline. Prior to the *Europe 20-20-20 Strategy and Climate Package*, this 20% energy efficiency goal was alluded to in the 2006 Commission Communication, *Action Plan for Energy Efficiency: Realising*

[27] **Wulfinghodd, Donald R.** *The Modern History of Energy Conservation: An Overview for Information Professionals.* Energy Institute Press. Available at: http://www.energybooks.com/resources/modern_history_of_energy.pdf
[28] Ibid. p. 4.
[29] **Hawken, Paul; Lovins, Amory B., Lovins, L Hunter**. *Natural Capitalism.* Little, Brown & Company, 1999

the Potential.[30] Regarding the efficiency target, in 2008, the European Commission published its communication *Energy Efficiency: Delivering the 20% Target*, which placed an emphasis on improving energy efficiency in the building sector, given that buildings are "responsible for about 40% of the EU's total final energy consumption and 36% of the EU's total CO2 emissions."[31]

Considering the substantial energy consumption of buildings, a number of documents were designed in order to improve their energy performance, including the *Energy Performance of Buildings Directive* in 2010 (which followed a revision of Directive 2002/91/EC focusing on buildings). In 2012, the European Commission adopted the *Delegated Regulation (EU) No 244/2012* which supplemented the previous directive from 2010. The delegated regulation makes it known that it is up to the member states to set energy performance requirements for buildings, and that this performance should be set through the consideration of cost-benefit analyses. It specifically states that "the cost-optimal level shall lie within the range of performance levels where the cost-benefit analysis over the lifecycle is positive." By the writing of this amendment, the European Commission sent a clear signal, that while there is an urgent need to improve the energy efficiency they also recognise that Member States should be able to target specific areas where the benefits of energy efficiency improvements outweigh the costs.

In 2011, the European Commission adopted the *Energy Efficiency Plan*, focusing on the need to reduce energy consumption in buildings, given their high consumption of total final energy. It highlights the need for increasing training for architects, engineers and technicians and the need to promote Energy Service Companies (ESCOs). The EC also wished to create instruments that link the profits of energy utilities to the amount of energy saved, rather than the amount used, and to promote cogeneration of heat and electricity. It also suggested that energy audits of industry and SMEs in particular are made mandatory and that energy and carbon taxes be used in order to achieve the 20% reduction in energy usage.

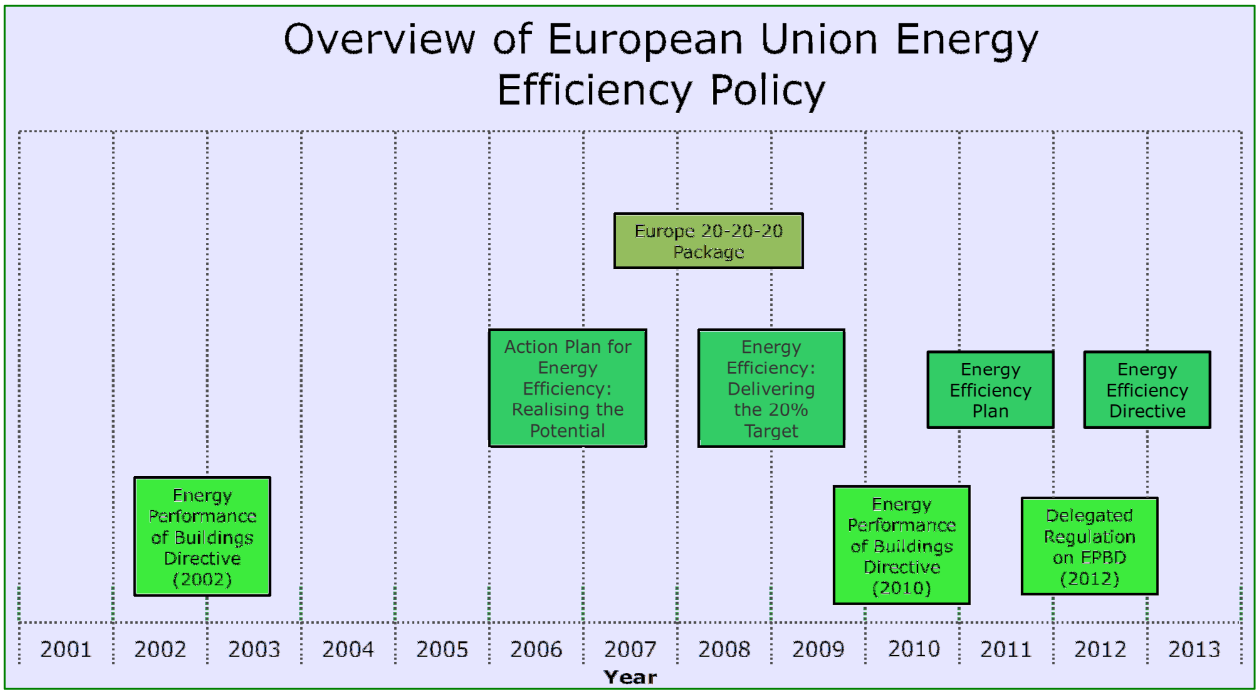
In April, 2012 the European Commission, in its 'non-paper' on the *Energy Efficiency Directive* recognized that it was only on track to achieve about half of its 20% energy efficiency target for 2020. In response to the lack of sufficient progress in reaching the target, the European Union adopted the full *Energy Efficiency Directive* in October, 2012. This directive requires energy companies to reduce end-use energy sales by 1.5% each year, the public sector to renovate 3% of public

[30] **European Commission Communication***: Action Plan for Energy Efficiency: Realising the Potential.* COM (2006) 545 final

[31] [31] **European Commission Communication***: Energy efficiency: delivering the 20% target*. COM (2008) 772 final

buildings over 500 m^2 (which will be lowered to 250 m^2 in 2015), and requires energy audits and management plans for large companies. Under this directive, if the EC is not satisfied with national indicative targets presented to them, they can ask member states to reassess their plans. All progress was planned to be assessed by 2014 in order to determine whether further steps are needed to reach the 20% goal and the potential inclusion of mandatory targets if non-binding targets prove to be ineffective. The timeline of these strategies are laid out below in Figure 7.

Figure 7 – Overview of European Union Energy Efficiency Policy



Source: Own Figure

In order for the European Union to meet its 20% energy efficiency target, the needed energy reduction equates to a reduction in primary energy consumption of 370 Mtoe compared to projections.[32] It is also defined as a maximum of 1483 Mtoe primary energy consumption, down from the projected 1,853 Mtoe for the entire European Union in 2020. While the energy efficiency target is not binding like the renewable energy and emissions targets, it is a stated goal of the European Commission and could become binding during future reviews.

[32] **European Council Directive 2013/12/EU adapting Directive 2012/27/EU of the European Parliament and of the Council** *on energy efficiency by reason of the accession of the Republic of Croatia* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:141:0028:0029:EN:PDF

There are, of course, a number of other policies and actions which apply to energy efficiency but which do not specifically focus on buildings. These include product regulations and energy performance labels, CO2 performance standards for cars and vans, the financing of energy efficiency through EU structural funds, Horizon 2020 and the European Energy Efficiency Fund, the usage of smart meters, and the EU Emissions Trading System.[33][34][35][36] These have been intentionally left out of the focus of this work, which focuses solely on energy efficiency of buildings.

In 2014, the European Commission published its Communication *Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy*.[37] In this document, the EU has proposed an energy efficiency target of 30% by 2030, against a baseline. The European Commission has found that at its current rate, between an 18% and 19% increase in energy efficiency by 2020 is expected.

This same communication notes that "The majority of the energy-saving potential is in the building sector, with 40% of the EU's energy consumption coming from buildings, and almost 90% of EU building floor space being privately owned and more than 40% of residential buildings dating from before 1960."[38] It also stated that the transposition of the *Energy Performance of Buildings Directive* (the most important piece of EU legislation related to energy efficiency in buildings) had not been fully implemented. A report from the European Commission in 2013 titled *Progress by Member States towards Nearly Zero-Energy Buildings* is the basis for this claim, which found that Member States have not made the progress needed to achieve the targets for "nearly zero-energy buildings" by 2020. As a result, the Commission has brought court proceedings against some Member States who are significantly lagging behind on this implementation.

The European Union aims to achieve ambitious greenhouse gas reductions targets by 2020, 2030 and 2050 (see Table 1).

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[33] **European Parliament Directive** 2009/125/EC
[34][34] **European Parliament Regulation (EU) No 333/2014 and Regulation (EC) No 443/2009**

[35] **European Parliament Directive 2009/72/EC**
[36] **European Parliament Directive 2009/29/EC and Decision No 1359/2013/EU**
[37] **COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL:** *Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy*. COM (2014) 520 final.
[38] Ibid.

Table 1 - European Union Greenhouse Gas Reduction Targets

Driver	2020[39]	2030[40]	2050[41]
GHG Reduction Target**	20%	40%	80-95%

Source: Own Table

The recent communication on energy efficiency makes it quite clear that the Commission is well-aware of the economic implications of placing overly burdensome regulations on the private sector, and has tried to strike a middle-ground between its energy and environmental goals and its economic ones. While technological innovation can help keep the costs down of meeting these goals, it is also likely that the marginal cost of each additional unit of energy saved, or unit of greenhouse gas prevented, will increase as the upper physically possible threshold is reached. However, the multi-pronged approach of supporting renewable energy technology and roll-out, in parallel with radical energy efficiency improvements, can help "burrow under" the cost barrier.[42] In the case of buildings, this can be done by increasing building envelope heat retention, as well as that of doors and windows, which reduce the need for high output and expensive oil, electrical or natural gas, heating and cooling systems. In their stead, they can be replaced with smaller, less demanding systems (that can either partially or totally defray the costs of the envelope, door and window improvements) that run off of locally produced renewable energy and/or which create fewer burdens on the electricity grid, while reducing the dependence of Europe on foreign energy sources. Also, beyond the environmental and health implications of greening the economy, given the fact that the price of oil has fluctuated wildly over in recent years, the economic and political uncertainties of failing to transition to self-reliant energy in the future are clear.

2.2 Review of Bulgarian Legislation and Initiatives

According to the *Energy Efficiency Directive of the European Union,* national targets for energy efficiency in EU Member States must be developed by national authorities. In their development they are to consider

- the potential for cost-effective energy savings;
- GDP forecasts;
- changes in energy imports and exports;
- development of all sources of renewable energy, nuclear energy and CCS;

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[39] **European Commission Communication**, *Limiting Global Climate Change to 2 degrees Celsius - The way ahead for 2020 and beyond* COM(2007) 2

[40] **European Commission Communication,** *A 2030 framework for climate and energy policies*, COM(2013) 169 final

[41] **European Commission Communication.** *Energy Roadmap 2050*, COM(2011) 885 final

[42] **Hawken, Paul; Lovins, Amory B., Lovins, L Hunter**. *Natural Capitalism.* Little, Brown & Company, 1999

- early action.

Member states must provide national indicative energy efficiency targets to the European Commission. According to its reported targets, Bulgaria aims to reduce the energy intensity of its economy by 50% by 2020 – from its 2005 level of 913.3 Mtoe/M€05, to 456 Mtoe/M€05. The goal is to consume 15.8 Mtoe (from a baseline scenario of 21.6 Mtoe) in primary energy in 2020, and 9.16 Mtoe (from a baseline scenario of 11.1 Mtoe) in final energy consumption.[43] This equates to a reduction in primary energy consumption of 5.8 Mtoe and 1.94 Mtoe final energy consumption compared to the baseline scenario in 2020. Under both the baseline scenario and the energy efficiency maximising scenario, this is to happen all whole Bulgarian GDP is expected to increase by 58.5% by 2020 compared to 2005.[44]

Depending on a number of factors for each member state, the *EU's Climate and Energy Package* dictates that greenhouse gas emissions are allowed to increase by up to 20% in some Member States and should decrease by at least 20% in others. In Bulgaria, a 20% increase in greenhouse gasses is allowed by 2020 and 16% of the gross final consumption of energy should come from renewable energy sources.[45] As will be shown below, such a target is irrelevant for Bulgaria since most credible estimates have its emissions levels decreasing by 2020.

Bulgaria has a number of action plans, strategies, laws, acts, funds and programs related to the improvement of energy efficiency and emissions reductions in the country. The country signed the United Nations Framework Convention on Climate Change in 1995. Following this, it ratified the Kyoto Protocol in 2002, aiming to reduce greenhouse gases by 8% by 2012 compared to 1988 levels. As part of this commitment, Bulgaria was required to elaborate *National Action Plans on Climate Change*.

Bulgaria's *Second National Action Plan on Climate Change* covers the years from 2005-2008. It reiterates the Bulgarian government's commitment to be a partner in the international communities' efforts to mitigate climate change through its ratification of the United Nations Framework Convention on Climate Change (UNFCC) and the Kyoto Protocol. [46] It is a plan which aims to lay out measures which are not unduly burdensome to the state, but which still allow it to meet its commitments. In terms of the residential sector, the plan praised the efforts of national programmes which improved the thermal insulation of buildings and the replacement of lamps with condensed fluorescents. However, the plan appeared to

[43] The baseline scenario is based on the following study: **National Technical University of Athens**, *Bulgaria: Baseline 2009, Analytical Results*, PRIMES Ver. 4 Energy Model, 23.12.2009

[44] Reply to the European Commission's query EU Pilot No 5047/13/ENER. Retrieved on Sept. 3rd, 2014.

[45] **European Commission**, Renewable Energy Progress Report, COM(2013) 175 final

[46] *Second National Action Plan on Climate Change, 2005-2008*, Council of Ministers of the Republic of Bulgaria (in Bulgarian).

focus more on switching to renewable or low-emitting energy sources than on energy efficiency measures in the residential sector.

A summary of the report noted that:[47]

> *Reducing or maintaining $C0_2$ emissions may be done as "no regret" at minimal costs now because in the years to come the marginal costs of future reduction measures will increase. The best approach for Bulgaria to maintain GHG emissions levels low is by avoiding carbon-intensive economic growth to the extent possible.*

The Third National Action Plan on Climate Change defines the actions that should be undertaken between 2013-2020 to address Bulgarian commitments within the *United Nations Framework Convention on Climate Change*, the *Kyoto Protocol* and the *European Union's Climate and Energy Package*.[48] The document notes that energy efficiency in households is an important area for addressing climate-related issues, as the residential sector consumes 25-26% of final energy. The document identifies measures which should be put in place to increase energy efficiency in households, including increased gasification, improvement of energy characteristics of buildings, increased efficacy of heating systems, and decentralised energy production through the use of renewables. The action plan estimated the aggregate GHG emissions in Bulgaria in 2009 to be 59.496 $MtCO_2e$. With all measures already approved by that year, it estimated emissions in 2020 to be 61.864 MtCO2e and in 2030 it put this figure at 60.943 MtCO2e. Including the adoption of all future measures that the action plan outlined after 2009, it foresaw the potential for reductions to 54.578 Mt CO2 eq. in 2020 (a reduction of 7.286 Mt CO2 eq.) and 52.642 Mt CO2 eq. in 2030 (a reduction of 8.301) Mt CO2 eq.

A review of one of the earlier pieces of modern legislation in the country includes the Bulgarian *Law on Energy* (2003).[49] It revealed that it does not focus on energy efficiency in the residential sector, and was not intended to. Rather it aims at defining a framework for the regulation of the sector, specifically for the generation and transmission of energy, as well as the use of renewable energy sources. Mainly, it governs the relationships and powers of state bodies in "defining of the energy policy, regulation and control functions."

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[47] *Second National Action Plan on Climate Change Strategy Summary*, Informal Thematic Debate on Climate Change as a Global Challenge – United Nations General Assembly 61st Session.
[48] *Third National Action Plan on Climate Change*. Website of the Ministry of Environment and Water of Bulgaria. Retrieved on January 2nd, 2014 from www3.moew.government.bg/files/file/Climate/Climate_Change_Policy_Directorate/THIRD_NATIONAL_ACTION_PLAN.pdf
[49] *Law on Energy*, Promulgated in State Gazette Nr. 107 of 9 December 2003. Retrieved on January 3rd, 2014 from: http://www.erranet.org/index.php?name=OE-eLibrary&file=download&id=2946

As we look more intensely at energy efficiency policy in the country, we see that *Energy Efficiency Act* of 2004 established the Energy Efficiency and Renewable Sources Fund (EERSF).[50] Among other things, the act also stipulated that government policy should be based on national long (every 10 years) and short-term programmes (every three years) passed by the Council of Ministers. These programmes, some of which are listed below, should "contain the objectives, measures for energy efficiency, activities of the executive branch, funding sources, terms of implementation, indicators of achievement of results, as well as other necessary data."

The *Bulgarian Energy Efficiency Fund* (BEEF) fund was originally financed through grants from a number of organizations including the World Bank, the Austrian Government, the Bulgarian government and private companies. The fund is an independent legal entity and acts as a lending institution, a guarantee facility and provides consulting services to companies, public institutions of individuals in helping them to develop and finance their energy efficiency projects. By September 1st, 2013, the BEEF had financed 160 projects worth 64.8 million BGN of which 43.87 came from the BEEF. It had also provided 32 credit guarantees worth a total of 22.9 million BGN, of which 3.8 million BGN came from BEEF.[51]

As ordered by the Energy Efficiency Act of 2004, the *National Long-Term Energy Efficiency Programme 2005–2015* was written in 2005. It provided a prognosis that final energy consumption in 2015 would be 15,926 Ktoe and that final energy intensity would be .157 koe/€00p.[52] In order to ensure that the targets laid out in the long-term plan were met, shorter term action plans were also designed and implemented. The first of these included the *National Short-Term Energy Efficiency Program 2005 – 2007* (2005).[53] This document specified the objectives and actions needed to meet the goals under the national long-term energy efficiency program. The program notes that

> *"as a result of its implementation fuel and energy equivalent to 140 thousand toe will be saved which is about 1.5% of the country's FEC in 2003 or about .75% annually saved fuel and energy for the end consumers…an important result of the program realization is the quantity of saved emissions of greenhouse gases, amounting to 600 thousand tones CO_2."* (Translated from Bulgarian).

[50] *Law on Energy Efficiency*, Promulgated in the State Gazette N 18/5 March, 2004, amended SG. 74/8 September 2006; amended SG 55/6 June 2007. Retrieved on January 3rd, 2014 from: http://old.mee.government.bg/eng/norm/rdocs/mdoc.html?id=190688
[51] Website of the Bulgarian Energy Efficiency Fund. Retrieved on January 3rd, 2014 http://www.bgeef.com/display.aspx?page=case_stud
[52] **Bulgarian Agency for Energy Efficiency**. *National Long-Term Energy Efficiency Programme 2005–2015* , Retrieved Aug. 25th, 2012 from: http://www.seea.government.bg/documents/NATIONAL_EE_PROGRAMME-last17.06.pdf
[53] Obtained from an employee of the Ministry of Environment and Water.

It is the *Law on Energy Efficiency*, passed by the Bulgarian government in 2008, which laid the groundwork for end-use energy efficiency and harmonised Bulgarian legislation with that of the EU.[54] The law notes that a national energy savings target should be split between retail energy sales companies, building owners and the owners of industrial systems. The law also stipulated that energy certifications are mandatory for buildings which are larger than 1,000 square meters including state-owned and municipally-owned buildings. It also states that the National Assembly should adopt a *National Energy Efficiency Strategy of the Republic of Bulgaria*, and that this should indicate what that national target for energy efficiency as well as the methods for achieving the target. This should be updated every five years. Based on this strategy, National Action Plans should lay out the specifics of the implementation of the strategy, including analysis and evaluation of the preceding national action plan, indicative energy savings targets, energy efficiency activities and planned measures (including the obligations of government in implementing these measures) as well as the obligations of individual persons, deadlines, sources and financing and reporting on achieved results.

In 2011, the *Energy Strategy of the Republic of Bulgaria till 2020 – For Reliable, Efficient and Cleaner Energy* was developed. [55] The document notes that there is no legally binding energy efficiency target set by the European Union, and that the indicative target set by the government is to reduce the energy intensiveness of GDP by 50% in 2020 compared to 2005. If the strategies goals are met, this will mean 456 toe of energy will be consumed per million Euros created (in 2005 inflation adjusted currency). This is compared to 913.3 toe per million Euros in 2005. The document aims to improve energy efficiency quite substantially (by around 25%) which would save nearly 6 million toe of primary energy in comparison with a reference BAU scenario in 2020. The document mentions that "energy efficiency is the highest priority in the country's energy policy." The document noted that this should be achieved through the promotion of energy savings by end-users, particularly in households, transport, industry and services.

The *First National Energy Efficiency Action Plan 2008-2010* (2007) was developed as a requirement of the Energy Services Directive (ESD) which was repealed by the Energy Efficiency Directive in 2012.[56] The ESD applied to the years from 2008-2016 within which the aim was for all Member States on average to achieve final energy reduction of 9% from the average consumption of the period from 2001-2005 for

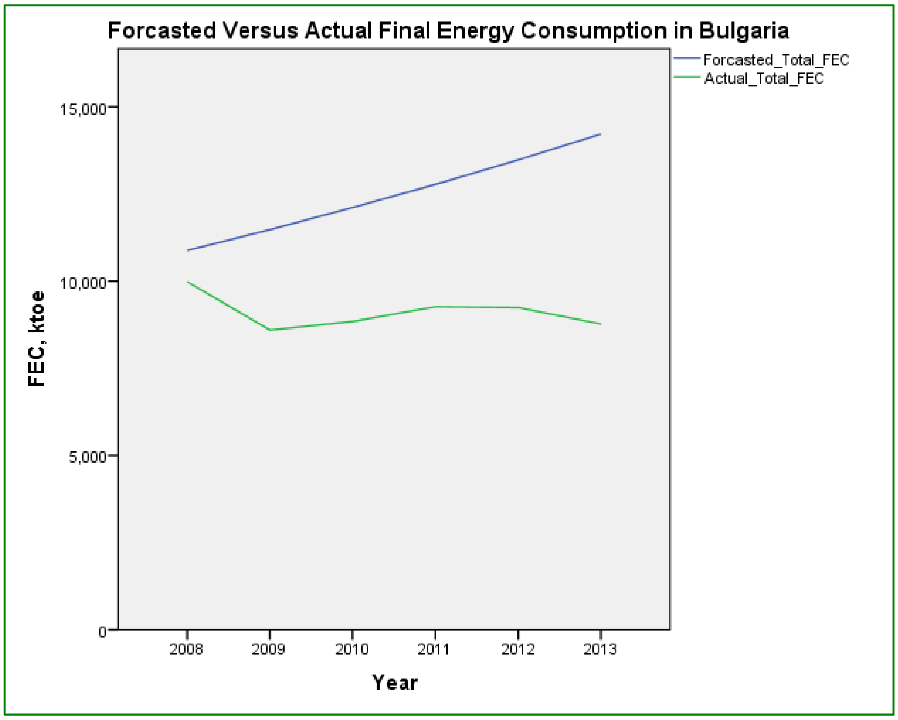
[54] *Energy Efficiency Act* (2008). Retrieved from the Ministry of Economy and Energy Website on January 3rd, 2014: www.mi.government.bg/files/useruploads/files/zee_en.pdf

[55] Ministry of Economy, Energy and Tourism (June, 2011), Retreived on January 6th, 2014 from: *http://www.wec-bulgaria.org/en/energy_info_files/strategy.pdf*

[56] First National Energy Efficiency Action Plan 2008-2012 (2007). Retrieved on January, 6th , 2014: http://www.seea.government.bg/documents/First_Energy_Efficiency_Action_Plan_EN.pdf

energy not included within the European Union's Emissions Trading Scheme (ETS). By the end of this first action plan in 2010, 3%, or 209 Ktoe/y FEC, was expected to be saved in Bulgaria (with 12,108 ktoe gross final inland energy consumption projected to be consumed by the country as a whole), and with 61 Ktoe/y (29%) of this savings to come from households. By 2013, 418 Ktoe/y was planned to be prevented against a total baseline usage of 14,217 Ktoe and by 2016, 627 Ktoe/y (out of a total of 16,695 Ktoe). These projections have turned out to be inaccurate, as shown in Figure 8 below, which compares forecasted data to actual data.

Figure 8 – Forecasted Versus Actual Final Energy Consumption in Bulgaria



Source: Own Table Using Data from First National Energy Efficiency Action Plan 2008-2010, Eurostat – Final Energy Consumption by Sector, and SPSS

This results from the fact that the *First National Energy Efficiency Action Plan 2008-2010* had a fairly straightforward way of making the calculation for energy consumption projections, by linking final inland energy consumption to the GDP growth rate for the years 2008-2016, which the document held to be an average of 5.5% up through 2016. However, a direct linkage between energy consumption and GDP is tenuous, in part because it assumes that GDP will be constant and that it is directly correlated with energy usage, when in fact structural changes in the economy (such as changes in the shares of contributions to the economy from the industrial to the financial sectors) can decouple these two indicators. When the report was written in 2007, GDP was growing at 6.4% per year. However, given the effects of the global financial crisis, GDP growth between 2010 and 2012 has averaged 1%, making baseline forecasted estimations of consumption higher than actual energy consumption rates could be expected to be, and rendering the forecasts of final energy consumption much higher than they would be if more accurate economic growth figures were used. In effect, this means that such figures are effectively unusable for gauging improvements in energy efficiency against a baseline, since reductions in energy usage would be seen from this baseline simply as a result of the baselines overestimation of energy consumption growth.

The *Second National Energy Efficiency Action Plan 2011-2013* (2011) noted that, by 2010, 305 ktoe FEC had been saved – almost 46% higher than the stated target of 209 ktoe FEC.[57] By the end of this second action plan's duration in 2013, 6% of the 9% target should have been achieved, amounting to 418 ktoe FEC, and the document forecasted that 507 ktoe FEC were expected to be saved by 2013. In the *National Energy Efficiency Action Plan 2014-2020*, based on the Energy Efficiency Directive, calculations showed that while this was not quite achieved, as savings of 471.5 ktoe FEC between 2008 and 2013 were seen, the 2013 target was still substantially exceeded the target outlined in the *First National Energy Efficiency Action Plan* of 418 ktoe FEC by 13%.[58]

The *National Energy Efficiency Action Plan 2014-2020* appears to correct the forecasted FEC projections until 2016 from *First National Energy Efficiency Action Plan 2008-2010* and the *National Long-Term Energy Efficiency Programme 2005–2015.* It notes that the reference scenario for FEC for 2012 is 9,044 ktoe, 9,200 ktoe for 2016, and 9,355 for 2020 which appear to be much more in line with recent trends. It also notes that between 2014 and 2016 an energy savings target of 358 ktoe is projected and between 2014 and 2020, 716 ktoe is projected. Such targets are assesses using bottom-up calculation methods by viewing the benefits of individual projects and programmes.

Some of the targets for 2016 and 2020 from the above stated documents are listed in Table 2.

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[57] Second National Energy Efficiency Action Plan *(June, 2011).* www.seea.government.bg/documents/Second_Energy_Efficiency_Action_Plan_EN.pdf

[58] Republic of Bulgaria, Ministry of Economy and Energy, National Energy Efficiency Action Plan 2014-2020. Retrieved from http://ec.europa.eu/energy/sites/ener/files/documents/2014_neeap_en_bulgaria.pdf

Table 2 – Targets Listed in Policy Documents

Name of Document	Target in Document
Third National Action Plan on Climate Change	61,864 kt CO_2e emissions by 2020 with "scenario with existing measures". (-7.8% compared to 2005) 54,578 kt CO_2e emissions by 2020 with "additional measures" (-18.7% compared to 2005)
Energy Strategy of the Republic of Bulgaria till 2020	Save 5.8 million toe of primary energy in comparison with a reference BAU scenario in 2020
First National Energy Efficiency Action Plan 2008-2010 (2007)	627 Ktoe of energy savings in final energy consumption by 2016

Source: Own Table

Under the more recent *Energy Efficiency Directive*, the *Second National Energy Efficiency Action Plan* continued the original calculation logic however. Long after it was recognised that GDP growth would be much slower than predicted during 2007, when the development of targets for the *First Action Plan* were completed, baseline assumptions for economic growth were not changed since the calculation logic was dictated at European level and remained for all member states. This highlighted the difficulty in setting future energy efficiency targets and also that caution should be exercised when implying a causal relationship between policy and the meeting of energy efficiency targets. In short, it is not possible when the assumptions used to calculate business as usual emissions projections do not hold true and are not updated with new data. When GDP growth stalls, final energy consumption is inevitably affected due reduced economic activity and cannot be ascribed to well-designed public policy and implementing measures.

This is problematic for the current investigation, since we rely heavily on forecasting energy usage and/or emissions towards 2020. More precise measurements are needed to create a baseline against which the costs for reducing specific amounts of emitted greenhouse gasses or energy usage can be measured. More accurate baselines for energy emissions forecasts can be constructed by using the indicators of population growth, GDP per capita growth, changes in the energy efficiency of the economy, as well as the carbon efficiency of energy. This is undertaken in the next section.

Taken altogether, the most recent energy efficiency targets in terms of energy saved is 5.8 Mtoe of primary energy compared to a baseline in 2020 and 7.286 Mt CO2 eq. of emissions prevented with in a scenario with "additional measures". Admittedly, the plethora of strategies, laws and targets, as well as the measurement of energy efficiency itself is complex. The estimations of energy savings rely on the development of robust baselines against which the success or failure of energy efficiency measures are evaluated. As a result of the plethora of extrapolations made for CO_2 consumption in Bulgaria, we constructed our own baseline estimation. Following this, abatement cost models were applied to calculate the costs of various levels of carbon mitigation cutbacks and how much abatement is possible through building envelope refurbishment in Bulgaria. Finally, existing financial outlays for energy efficiency measures in the residential sector were assessed against this estimation, aiming to evaluate what further steps to unlock this potential are necessary.

II. Methods for Calculating Emissions and Abatement Costs

1. Calculating Emissions for 2020

Emissions projections for Bulgaria through 2020 must be determined and used as a baseline against which potential emissions reductions can be calculated. William Cline has developed an approach that considers population growth rates, changes in per capita income, changes in the rate of energy efficiency, and changes in the carbon intensity of energy production over a defined period of time in helping to construct such a baseline. The equations used to determine these components are found below (see Equations below).[59]

Equation 1 – Calculating Population in Year t

$$N_t = N_0 e^{nt} \tag{1}$$

Where N_t is equal to the population in year t, N_0 indicates the reference year, n is the growth rate of the population.

Equation 2 – Calculating Real GDP Per Capita in 2005 PPP Dollars

$$q_t = q_0 e^{gt} \tag{2}$$

Where q_t is the GDP per capita in 2005 PPP dollars in year t, q_0 is the reference year, and g is the growth rate of per capita income.

Equation 3 - Output per Unit of Energy

$$\lambda_t = \lambda_0 e^{wt} \tag{3}$$

Where λ_t equals the output per unit of energy (energy efficiency) in year t, λ_0 is the reference year and w is the annual rate in increase in energy efficiency.

Equation 4 - Energy per Unit of Carbon Dioxide

$$\gamma_t = \gamma_0 e^{ct} \tag{4}$$

Where γ_t equals the energy per unit of carbon dioxide (carbon efficiency) in year t, γ_0 is the reference year and c is the annual rate of increase in carbon efficiency of energy.

Equation 5 - Emissions of Carbon Dioxide in Year *t*

[59] **Cline, William R.**, *Carbon Abatement Costs and Climate Change Finance, 2011, pg. 8.*

$$E_t = \frac{N_0 e^{nt} q_0 e^{gt}}{\lambda_0 e^{wt} \gamma_0 e^{ct}} = \frac{N_0 q_0}{\lambda_0 \gamma_0}\ e^{(n+g-w-c)t} = E_o e^{(n+g-w-c)t} \tag{5}$$

This equation signifies the population in year *t* multiplied by the real GDP per capita in year *t.* This is then divided by the output per unit of energy (i.e. energy efficiency) in year *t* multiplied by the energy per unit of carbon dioxide (i.e. carbon efficiency). Here, E_t is equal to the percentage change in carbon dioxide emissions in year *t* compared to E_0. When E_0 (emissions in base year) is substituted for $\frac{N_0 q_0}{\lambda_0 \gamma_0}$ then E_t is equal to the actual level of emissions in year t.

From this, Cline shows that annual rates of change of emissions can be decomposed to the following equation:

Equation 6 – Annual Rate of Change of Emissions

$$\acute{E}t = n + g - w - c \tag{6}$$

In this instance, $\acute{E}_t$ equals the annual percentage change of emissions over the time period. For Bulgaria, we now turn to calculating the values of *n*, *g, w* and *c* for the period 2015-2020.

1.1 Calculating Population Growth (*n*)

It follows that we must first calculate the average population growth rate in Bulgaria between 2015 and 2020. There are two ways that this has been approximated in order to ensure the robustness of the data. The first of these is by using forecasted population figures from the U.S. Census Bureau, which were developed through the Cohort-Component Method and which considers age and sex-related mortality, fertility and migration (see Table 3).

Table 3 - Change in Bulgarian Population Growth Rates, 2015-2020[60]

Change in Population - Bulgaria			
Year	Midyear Population (in thousands)	% Change - Year on Year	Average Yearly % Change For the Period
		Formula: $\Delta\%=((X_1/X_0)-1)*100$	**Formula: $\Delta\%=(\Delta_0+\Delta_1+\Delta_2...\Delta_f)/X_{total}$**
			-0.875745791
2011	7094		
2012	7038	-0.789399493	
2013	6982	-0.795680591	
2014	6925	-0.81638499	
2015	6867	-0.837545126	
2016	6809	-0.844619193	
2017	6750	-0.86650022	
2018	6690	-0.888888889	
2019	6630	-0.896860987	
2020	6569	-0.920060332	
	Data: US Census Bureau International Database - http://www.census.gov/population/international/data/idb/country.php	Forumla: Where X_0 is the base year and following year is X_1	Formula: Where Δ_0 is the start year, Δ_f is the end year in the time series and where X_{total} is the total number of years in the series

Source: Own Table from U.S. Census Bureau Data

In order to calculate the average population growth rate, the percentage change between years from 2015-2020 was calculated and then averaged. From this, it was found that **the average year-on-year population growth rate for the 6 year period was -.88%.** Using the projected population growth rate of -.88% between 2015 and 2020, and applying the equation provided by Cline, we find a calculated population that is nearly identical (.000024% less) in 2020 than that projected by the U.S. Census Bureau. This allows for confidence in the predictive power of the Cline equation and can possibly be attributed to different rounding logics.

Using Eq. (1), we find that:

$$N_6 = 6925e^{-.0088*6}$$

Or:

$$N_6 = 6568.84$$

Another estimation was done using Bulgarian population data from the US Census Bureau from 1990-2014, and applying a forecasting model using IBM's Statistical Package for the Social Sciences (SPSS). The forecasting model type used was the Damped Trend Model (see Table 4). This model has been shown to be one of the most accurate in terms of forecast accuracy across datasets.[61]

[60] Data: *US Census Bureau International Database* - http://www.census.gov/population/international/data/idb/country.php

[61] **Gardner, Everette S., McKenzie, Eddie**. *Why the Damped Trend Works*, October 22nd, 2009.

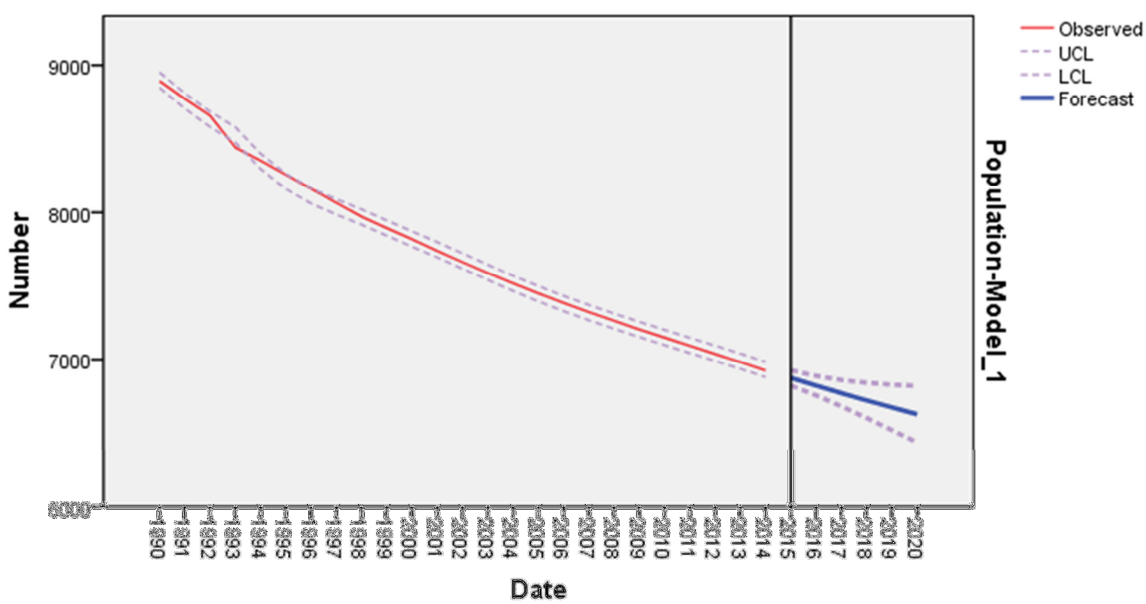
Table 4 - Population Forecast 2015-2020 - Damped Trend Model

Population Forecast - Damped Trend Model							
Model		2015	2016	2017	2018	2019	2020
Population-Model_1	Forecast	6875	6822	6772	6722	6675	6629
	UCL	6927	6889	6861	6842	6829	6821
	LCL	6823	6756	6682	6603	6521	6437

Source: Own Table

The table contains both Upper Control Limits (UCLs) and Lower Control Limits (LCLs). The UCL is defined as the value above the forecasted value equal to three times the standard deviation, and the UCL is equal to the forecasted value three times below the standard deviation. Nearly all (99.73%) of all future deviations in population will fall between the UCL and LCL, where only common causes of variation remain (i.e. the data is in statistical control). As can be seen in Figure 9 below, the only time when the observed population fell outside of the UCL and LCL was between 1992 and 1993, a very tumultuous time for the country where there were non-standard sources of natural variation due to systemic socio-political changes. The model becomes also less predictive over time, which explains the widening UCL and LCL towards 2020.

Figure 9 – Visualised Forecast of Bulgarian Population Until 2020 – Damped Trend Model



Source: US Census Bureau and Own Calculations Using SPSS

Using this forecasting method, we can see that N_{2020} is equal to 6,629,000. This would indicate that in the six year period between 2015 (total predicted population of 6,875,000) and 2020 (total predicted population of 6,629,000) that the population will decline by 3.58%, **with an average annual population growth rate for Bulgaria of roughly -.73%** (see Table 5)**.**

Table 5 – Average Yearly Population Change, 2015-2020 Using Damped Trend Model

Year	Forcasted GDP Per Capita	% Change	Average Yearly % Change
2015	6875		-0.72610031
2016	6822	-0.7709091	
2017	6772	-0.7329229	
2018	6722	-0.7383343	
2019	6675	-0.6991967	
2020	6629	-0.6891386	

Source: Own Table

Thus, for our value of *n*, we will use an estimated annual population growth of:

$$n=-.73\%$$

1.2 Calculating Growth Rate of GDP Per Capita (*g*)

The second part of the Cline equation involves calculating the growth rate of GDP per capita (*g*). For this calculation, Eurostat data was used (see Table 6). Throughout the period, the average year-on-year GDP-per-capita rise between 1990 and 2013 was approximately 10.8% and for 2004-2013 was approximately 8.8% (which calculated as a reference figure to exclude the years shortly after the transition period began).

Table 6 – GDP Per Capita Growth Rates in Bulgaria – 1990-2013

GDP Per Capita in Bulgaria			
Year	**GDP Per Capita (Euro)**	**% Change**	**Average % Change For Period**
		Formula: $\Delta\%=((X_1/X_0)-1)*100$	**Formula: $\Delta\%=(\Delta_0+\Delta_1+\Delta_2...\Delta_f)/X_{total}$**
1990	1,200		10.84252352
1991	500	-58.33333333	
1992	500	0	
1993	1,100	120	
1994	1,000	-9.090909091	
1995	1,200	20	
1996	800	-33.33333333	
1997	1,100	37.5	
1998	1,400	27.27272727	
1999	1,500	7.142857143	
2000	1,700	13.33333333	
2001	2,000	17.64705882	
2002	2,200	10	
2003	2,400	9.090909091	
2004	2,600	8.333333333	8.814873106
2005	3,000	15.38461538	
2006	3,400	13.33333333	
2007	4,000	17.64705882	
2008	4,600	15	
2009	4,600	0	
2010	4,800	4.347826087	
2011	5,200	8.333333333	
2012	5,500	5.769230769	
2013	5,500	0	
	Source: Eurostat - GDP and main components - volumes [nama_gdp_c]	Forumla: Where X_0 is the base year and following year is X_1	Formula: Where Δ_0 is the start year and Δ_f is the end year in the time series

Source: Own Table

Using the projected growth rate of GDP of 8.81% between 2004 and 2013, and Using Eq. (2) we find that

$$q_7 = 5500e^{.0881*7}$$

Or:

$$q_7 = 10190.42$$

As a result of the economic and political chaos of the early 1990s, there were uncommon causes of variation where the data was outside of statistical control which is why a more recent historical data set was deployed. However, Equation (2) calls for accurate forecasts of GDP per capita and it was found that given recent economic shocks and a relatively short amount of time (around 20 years) of free markets in the country, that year-on-year changes of this historical data had dubious predictive value. As such, an exponential smoothing model called the Brown Model, selected as the best fit by SPSS, has been used help address these variations and deliver more robust forecasts (see Table 7).

Table 7 – Forecasted GDP Per Capita – Brown Model

GDP_Per_Cap-Model_1 - Brown Model								
Model		2014	2015	2016	2017	2018	2019	2020
GDP_Per_Cap-Model_1	Forecast	5860	6116	6371	6627	6882	7138	7393
	UCL	6477	6927	7405	7905	8426	8965	9522
	LCL	5244	5305	5338	5348	5338	5310	5264

Source: Own Table

We can see a forecasted GDP per capita at market prices in Bulgaria of €5860 in 2014 and €7393 in 2020. **From this information, we can calculate the average annual GDP per capita growth rate for the seven year period between 2014 and 2020 at 3.95% annually,** and a total rise of 26.19% over the period (see Table 8).[62]

Table 8 - Average Yearly Change in GDP Per Capita, 2015-2020 Using Brown Model

Year	Forcasted GDP Per Capita	% Change	Average Yearly % Change
2014	5860		3.949395509
2015	6116	4.36860068	
2016	6371	4.16939176	
2017	6627	4.0182075	
2018	6882	3.84789498	
2019	7138	3.71984888	
2020	7393	3.57242925	

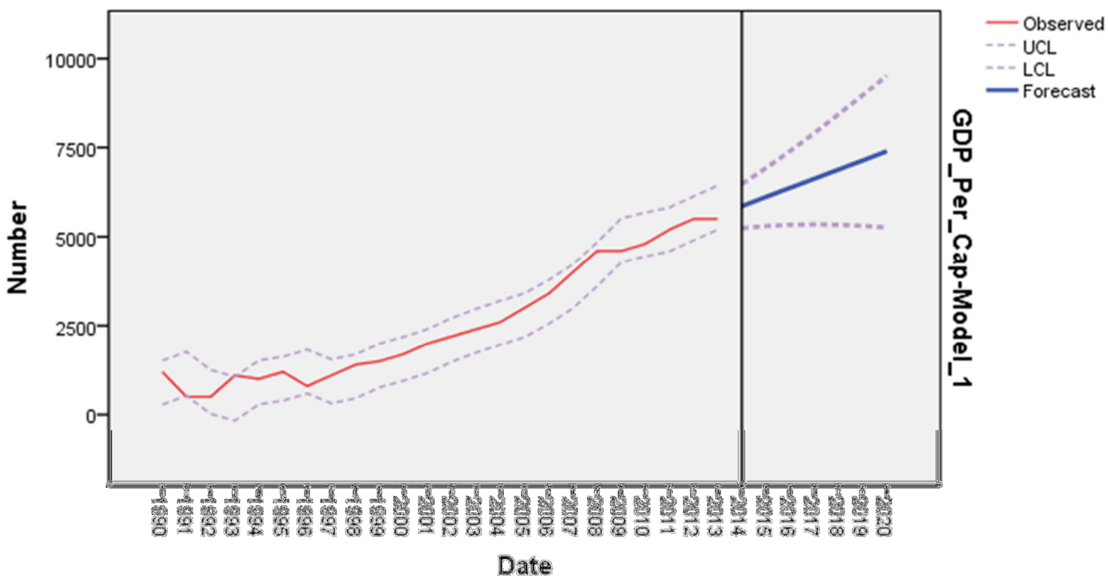
Source: Own Table

We also see that the UCL for 2020 is slightly lower than the calculation in Equation 3 above – indicating that the usage of historical data and the Cline Equation in this instance is not effective in forecasting this variable. This is probably due to the fact that, unlike the calculation for population growth, the data used here was historic rather than forecasted. According to the *National Reform Programme of Bulgaria*, updated in 2014, GDP growth in Bulgaria is expected to reach 2.1% in 2014 and is forecasted to be 2.6% in 2015, 3.4% in 2016 and 3.4% in 2017.[63] It is important to consider that these calculations are forecasted during a period of negative population growth, which could theoretically cause GDP per capita to rise in periods of stagnant of even negative GDP growth.

[62] As compared with the six-year period from 2015-2020 which is forecasted for population growth, a seven-year period is used here since no data was available for 2014.
[63] **Republic of Bulgaria, Ministry of Finance**, *Europe2020: National Reform Programme – 2014 Update,* April, 2014.

This data has been visualized below in Figure 10. Note the erratic nature of the data from 1990-1998, a period market by emigration and hyper-inflation that had significant effects on this indicator. Fitful data can also be seen in the years from 2008-2014 and likely resulting from fallout from the global economic crisis.

Figure 10 – Visualized Forecast of GDP Per Capita in Bulgaria, 2014-2020 – Brown Model



Source: Eurostat Data and Own Calculations Using SPSS

As another reference figure to ensure the robustness of the findings predicted by the Brown approach, the International Monetary Fund forecasted that in 2014, GDP per capita would be $7,574.16 U.S. dollars in constant prices, and by 2019, this figure would be $8,959.67 – a 18.29% increase and a **3.2% average annual rise in U.S. current dollars** (see Table 9).

Table 9 - Average Yearly Change in GDP Per Capita, 2015-2020 Using IMF Data

Year	Forcasted GDP Per Capita	% Change	Average Yearly % Change
2013	7,417.61		3.20
2014	7,574.16	2.11054447	
2015	7,802.53	3.01507863	
2016	8,076.99	3.51758936	
2017	8,361.11	3.51758427	
2018	8,655.22	3.51758445	
2019	8,959.67	3.51758986	

Source: Own Table Based on IMF Data

There is some discrepancy between the annual predicted GDP per capita rises in the country using the Brown Model and IMF forecasts. The discrepancy is likely mostly attributable to difference in calculation logics and potentially the use of different historical data sets. Therefore, in staying in line with previous logic of using our own forecasting models, we will estimate the average growth rate of GDP per capita during the period to be:

$$g=3.95\%$$

1.3 Calculating Energy Efficiency Change (*w*)

When calculating the change in the growth of energy efficiency, Eurostat data for KOE per €1000 of output of the Bulgarian economy was used. Here, we can see that the average increase in energy efficiency, as measured by kilograms of oil equivalent per €1000 between the years of 2001 and 2012 was 3.84% (see Table 10).

Table 10 - Changes in Energy Efficiency of the Economy

Change in Energy Efficiency of the Bulgarian Economy			
Year	**Kilogram of oil equivalent per 1000 euro**	**% Change**	**Average % Change For Period**
		Formula: $\Delta\%=((X_1/X_0)-1)*100$	**Formula: $\Delta\%=(\Delta_0+\Delta_1+\Delta_2 \ldots \Delta_f)/X_{total}$**
2001	1,041.10		-3.844607635
2002	962.90	-7.51128614	
2003	942.00	-2.170526534	
2004	866.20	-8.04670913	
2005	849.40	-1.939505888	
2006	823.50	-3.049211208	
2007	759.9	-7.723132969	
2008	711.7	-6.342939861	
2009	661.4	-7.067584656	
2010	668.8	1.118838827	
2011	705.5	5.487440191	
2012	669.9	-5.046066619	
	Source: Eurostat Energy intensity of the economy [tsdec360]	Forumla: Where X_0 is the base year and following year is X_1	Formula: Where Δ_0 is the start year and Δ_f is the end year in the time series and where X_{total} is the total number of years on the series

Source: Own Table

When we model this data and forecast it out to 2020 using an ARIMA Model, we find that in 2020 it will require 399.94 KOE to produce €1000 in the country (see Table 11). Between 2015 and 2020, the energy intensity of the Bulgarian economy will fall by 30% - a quite impressive figure, but logical considering Bulgaria's currently inefficient economy and high starting point.

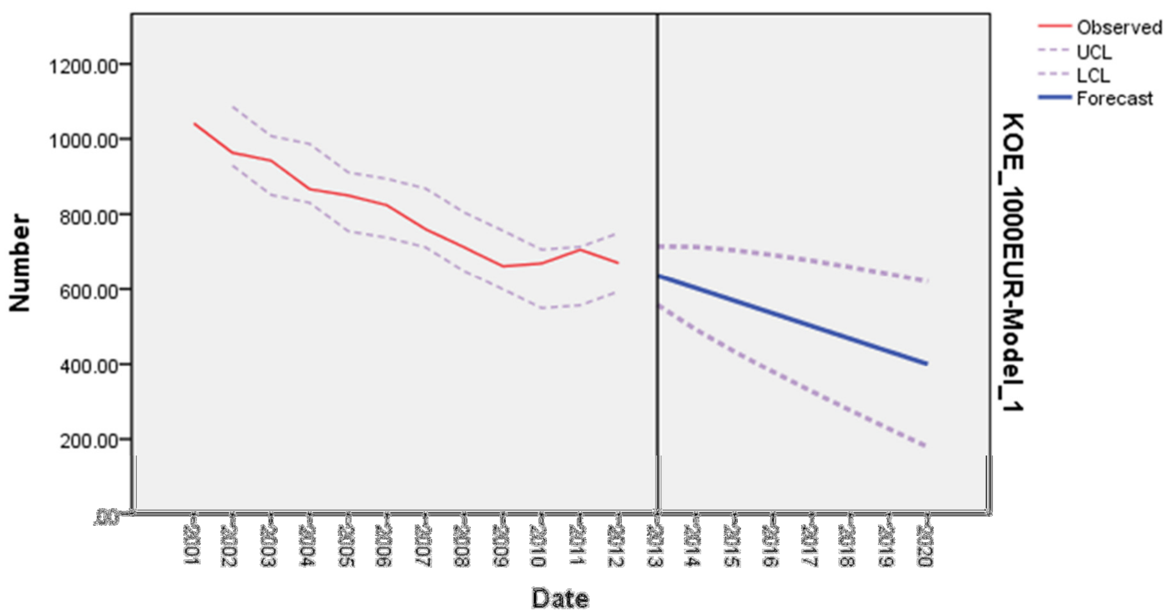
Table 11 – Forecasted KOE per €1000 Output from 2013-2020 – ARIMA Model

KOE_1000EUR-Model_1 - ARIMA Model									
Model		2013	2014	2015	2016	2017	2018	2019	2020
KOE_1000EUR-Model_1	Forecast	636.15	602.41	568.66	534.92	501.17	467.43	433.68	399.94
	UCL	714.27	712.88	703.97	691.15	675.85	658.78	640.36	620.89
	LCL	558.04	491.93	433.36	378.68	326.50	276.08	227.00	178.99

Source: Own Table

In Figure 11, this data has been visualised to include the Upper and Lower Control Limits as well as the observed data from 2001-2012.

Figure 11 – Visualized Forecast of KOE per €1000 Output from 2013-2020 – ARIMA Model



Source: Eurostat and Own Calculations Using SPSS

Average year-on-year forecasts for this data have been calculated (see Table 12).

Table 12 – Average % Change in Energy Efficiency of the Bulgarian Economy 2015-2020

Forecasted - Average Change in Energy Efficiency of the Bulgarian Economy, 2015-2020			
Year	**Forecasted KOE per 1000 euro**	**% Change**	**Average % Change For Period**
2014	602.41		-6.59638336
2015	568.66	-5.601750547	
2016	534.92	-5.934167826	
2017	501.17	-6.308526368	
2018	467.43	-6.733298264	
2019	433.68	-7.219402143	
2020	399.94	-7.781155015	

Source: Own Table

Since *w* is defined as the "rate of increase of energy efficiency", and a reduction in energy per unit of output is forecasted, we will reverse the sign of the value in Table 12, to find that:

$$w{=}6.60\%$$

1.4 Calculating Carbon Efficiency of Energy (*c*)

Calculating the carbon efficiency of energy is the fourth value needed to forecast the emissions rate using Cline's equation. Since no readily available data for this was found, a proxy was constructed using data on CO_2 equivalent emissions levels from the European Environment Agency, and gross inland energy consumption from Eurostat (see Table 13). The average year-on-year carbon intensity of energy decreased at a rate of -.68% between 1990 and 2012.

Table 13 - Changes in the Carbon Efficiency of Energy

Carbon Intensity of Energy							
Year	**Emissions 1 000 t of CO2 equivalent**	**Emissions tons of CO2 equivalent**	**Gross inland energy consumption 1 000 toe**	**Gross inland energy consumption toe**	**Ton CO2 Equivalent Emissions per Primary Energy Ton Oil Equivalent**	**Percent Change of Carbon Itensity of Energy Production**	**Average Δ% For the Period**
1990	109138.589	109138589	27,649.70	27649700	3.947188903		-0.681778317
1991	86325.854	86325854	22,255.50	22255500	3.878854845	-1.731208194	
1992	80125.689	80125689	20,651.80	20651800	3.87984045	0.025409687	
1993	78452.088	78452088	21,955.00	21955000	3.573313049	-7.900515609	
1994	74873.38	74873380	21,161.50	21161500	3.538188692	-0.982963351	
1995	75705.127	75705127	22,689.40	22689400	3.336585674	-5.697915937	
1996	75576.798	75576798	23,000.40	23000400	3.285890593	-1.519369982	
1997	71979.035	71979035	20,781.60	20781600	3.463594478	5.408088905	
1998	67071.525	67071525	20,213.10	20213100	3.318220609	-4.197196564	
1999	60264.016	60264016	18,287.40	18287400	3.295384582	-0.688201008	
2000	59470.846	59470846	18,522.60	18522600	3.210718042	-2.569246104	
2001	62642.814	62642814	19,295.70	19295700	3.246464964	1.113362229	
2002	59648.927	59648927	18,694.60	18694600	3.190703572	-1.717603368	
2003	64389.582	64389582	19,296.20	19296200	3.336904779	4.582099331	
2004	63592.221	63592221	18,940.50	18940500	3.357473192	0.616391972	
2005	63711.726	63711726	19,754.10	19754100	3.225240634	-3.938454641	
2006	64504.686	64504686	20,398.80	20398800	3.162180422	-1.955209498	
2007	68422.73	68422730	20,036.90	20036900	3.414836127	7.9899206	
2008	66842.7	66842700	19,926.50	19926500	3.35446265	-1.767975822	
2009	57725.268	57725268	17,504.10	17504100	3.297814112	-1.688751494	
2010	60272.038	60272038	17,769.80	17769800	3.391824219	2.850679368	
2011	65995.748	65995748	19,089.90	19089900	3.457102866	1.924588159	
2012	61045.626	61045626	18,233.30	18233300	3.348029485	-3.155051661	
	European Environment Agency - Greenhouse Gas - Data Viewer	Own calculations	"Source: Eurostat - Gross inland energy consumption by fuel type 1 000 toe (tsdcc320)"	Own calculations	Formula: CO2 Emissions/Total Consumption of Energy	Formula: $\Delta\%=((X_1/X_0)-1)*100$	Formula: $\Delta\%=(\Delta_0+\Delta_1+\Delta_2 \ldots \Delta_f)/11$

Source: Own Table

However, when this data was forecasted to 2020 it was found, using the Holt Forecasting Model that decreases in the carbon efficiency of the energy supply have been recorded (see Table 14 below). Note that *TnsCO2Eq_Over_TnOilE* below refers to the tons of CO2 equivalent emitted for each ton oil equivalent of gross inland energy consumed. This can be seen in the increasing values in the row entitled 'forecast'.

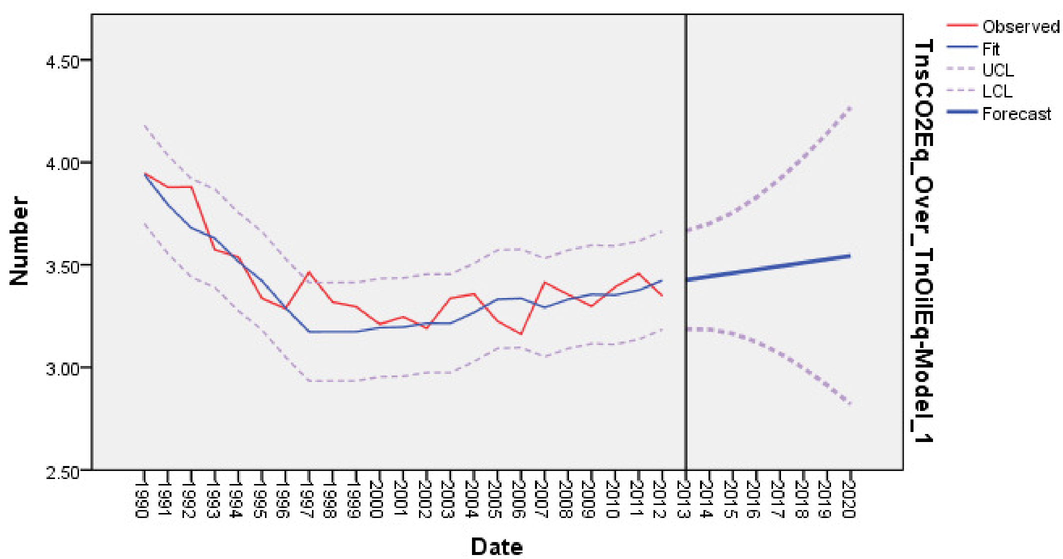
Table 14 – Average Percent Change in the Carbon Efficiency of Energy 2013-2020 Holt Model

Tons of CO2 Eq. Emitted Per Ton of Oil Equivalent - Holt Model									
Model		2013	2014	2015	2016	2017	2018	2019	2020
TnsCO2Eq_Over_TnOilEq-Model_1	Forecast	3.43	3.44	3.46	3.48	3.49	3.51	3.53	3.54
	UCL	3.67	3.70	3.76	3.83	3.92	4.02	4.14	4.27
	LCL	3.19	3.18	3.16	3.12	3.07	3.00	2.91	2.82

Source: Own Table

Despite this, when we look at a visualisation of this data in the graph below, we can see very large and diverging Upper and Lower Control Limits during the forecasted period after 2013. This reduces the predictive power of this forecast and the Cline equation more broadly, as we approach 2020. Given the weak relationship between time and the carbon intensity of energy, a best fit line has been added in this case to illustrate the gradual increase in the carbon intensity of energy starting around the year 1997.

Figure 12 - Tons of CO2 Equivalent Emitted for Each Ton Oil Equivalent of Gross Inland Energy Consumed from 2013-2020 – Holt Model



Source: European Environmental Agency, Eurostat and Own Calculations Using SPSS

Despite the unpredictability of this variable, we rely upon it to allow us to calculate an average change in the carbon intensity of energy production until 2020 (see Table 10).

Table 10 – Average % Change in the Carbon Efficiency of Energy for the Period from 2013-2020

Forecasted - Average Change in Carbon Efficiency of Energy in Bugaria, 2015-2020			
Year	**Carbon Efficiency of Energy (Ton C02 Eq. Per Ton Oil Eq.)**	**% Change**	**Average % Change For Period**
2014	3.44		0.478823157
2015	3.46	0.581395349	
2016	3.48	0.578034682	
2017	3.49	0.287356322	
2018	3.51	0.573065903	
2019	3.53	0.56980057	
2020	3.54	0.283286119	

Source: Own Table

Using the forecasted data, an average annual increase in carbon intensity of the energy supply is calculated at roughly .48% annually. Since the Cline equation defines this variable as the "annual rate of increase in carbon efficiency of energy" we reverse the sign since the carbon efficiency is forecasted to decrease.

c=-.48%

1.5 Change in Emissions Using Cline Equation

With all four variables calculated for the equation from Cline, we can now calculate the annual rate of change of emissions from 2015-2020 in Bulgaria using Eq. (6) such that

$$\acute{E}t = -.73 + 3.95 - 6.60 - (-.48)$$

$$\acute{E}t = -2.9$$

Thus, we calculate that the average annual change in the emissions rate for Bulgaria from 2015 until the end of 2020 is -2.9%. For comparison, according to Cline, for 25 economies accounting for 92% of global emissions in 2007, from 1990-2006, emissions rose annually by 1.8%. This occurred with a population growth of 1%, an annual per capita output growth of 2%, a 1.4% annual increase in the output efficiency of energy and almost no change in the carbon efficiency of energy.

The last official figure for emissions levels in Bulgaria from the Europe Environmental Agency was from 2012 and reported as 61,045.626 1,000 TCO_2e.[64]

[64] Clearly, it would be preferable to have an official figure for emissions levels in 2014 – this can be done once those official figures are available without much addition effort.

When applying the forecasted average annual rate of change between 2015 and 2020 we find that in the 8th year after 2012 – 2020, that

$$N_8 = 61{,}045.626e^{-.029*8}$$

$$N_8 = 48{,}405.89$$

Thus, using historical data and considering changes in population, GDP per capita, energy efficiency and the carbon efficiency of energy, we find that 48,405.89 Kilotons of CO_2e is forecasted to be emitted in 2020. In order to see how this figure compares to other emissions projections in 2020, figures from various sources have been aggregated.

Table 11 - Emissions Abatement Estimations in 2020

Source of the Estimation	Own Calculation Based on the Cline Model	EU Energy, Transport and GHG Emissions – Trends to 2050: Reference Scenario 2013[65]	Second National Action Plan on Climate Change[66]	Third National Action Plan on Climate Change (Scenario with additional measures)[67]	Third National Action Plan on Climate Change (Scenario with Additional Measures)[68]
Emissions in 1000t CO2 equivalent in 2020	*48,406*	*55,000*	*89,000*	*61,864*	*54,578*

Source: Own Table

It is important to note that the estimate in the *Second National Action Plan on Climate Change* was made in 2004 and based on official data up until 2002. It thus does not reflect changes resulting from the global financial crisis and other demographic, economic and social developments in the interim period. This figure has been included in order to show how current emissions projects for the country are much lower than was expected by policy-makers a decade ago.

[65] EU Energy, Transport and GHG Emissions – Trends to 2050: Reference Scenario 2013, European Commission DG for Energy. DG for Climate Action and DG for Mobility and Transport, 2013. Available at: http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2050_update_2013.pdf

[66] Second National Action Plan on Climate Change, Ministry of Environment and Water, Republic of Bulgaria, 2004. Available at: http://www.moew.government.bg/files/file/Climate/Climate_Change_Policy_Directorate/Second_National_Plan_CC_EN.pdf

[67] Third National Action Plan on Climate Change, Ministry of Environment and Water, Republic of Bulgaria, 2012. Available at: http://www3.moew.government.bg/files/file/Climate/Climate_Change_Policy_Directorate/THIRD_NATIONAL_ACTION_PLAN.pdf

[68] Ibid.

The estimations made in the *Third National Action Plan*, which was published in 2012, are much closer than the estimations made using the Cline Model and the scenario project by the *European Environment Agency*. For this *Third National Action Plan*, two figures are provided and based on different scenario assumptions about the implementation of existing and future measures. Despite this, projections using the Cline Model and the most recent economic and demographic data still fall below the even the most recent emissions projections for 2020. While the existing emissions projections from national and European level policy-makers could have been used as a projection against which potential energy efficiency improvements could be measured, we aimed to ensure that the most up-to-date figures were available to ensure the accuracy of our findings as well as to illustrate how carbon emissions projections could be constructed.

Since it will be necessary to calculate the amount of emissions that can be mitigated by basic envelope abatements between 2015 and 2020, we must find the total forecasted emissions in Bulgaria from 2015-2020 – and not only those forecasted for 2020. This can be achieved in a number of ways, such as by approximating or calculating the Area under the Curve (AUC) of

$$N_8 = 61{,}045.626e^{-.029t}$$

from 2015-2020 using the *Linear Trapezoidal Method* and also known as taking the *Riemann Sum*. In doing this, the height of each *Riemann Sum* under the curve can be described by evaluating a function at the left endpoint of each rectangle or by the midpoints or right endpoint. It can also be done more accurately, by evaluating the definite integral of the function between the years 2015 and 2020.

Using the *Riemann Sum* in the form of

Equation 7 - Riemann Sum Using Sigma Notation

$$Total\ Sum = \sum_{i=1}^{n} f(x_i)\Delta x\ , where\ \Delta x = \frac{b-a}{n} \tag{7}$$

where *i* denotes the number of the subinterval/rectangle under the curve to start summation, *n* equals the total number of subintervals or rectangles under the curve to use, *f*(x_i) is the height of the rectangle (or value of the function at point *i)* calculated by funding the value of the function *f(x)* at *i,* and where *Δx,* or the width of the rectangle is calculated by subtracting the rightmost point of the area being approximated (*b*) and subtracting the leftmost point (*a*) and dividing this by the number of rectangles *n where* a and b are continuous and non-negative.

Calculating the value of the emissions forecasting equation at the midpoint, as *i* goes from 3.5 to 8.5 (2015-2020) proceeds as $Total\ Sum = \sum_{i=3}^{5} f(xi) * 1$, where Δx =1 since the width of each rectangle is one year. This can be rewritten as

$$Total\ Sum = \sum_{i=3}^{5} f(xi)$$

Since we are calculating f(x) at the midpoint of the six rectangles (to give us a better approximation since using the left endpoint would overestimate the total and the right endpoint would underestimate the total) we add one half to *i* (the height calculation) and replace *x* with *i* such that

$$Total\ Sum = \sum_{i=3}^{5} f\left(i + \frac{1}{2}\right)$$

Using our function for emissions forecasts from Cline, (see Equation 9), and replacing *x* with *i+1/2* for *x* and summing the six rectangles we get

$$Total\ Sum = \sum_{i=3}^{5} 61045.626e^{-.029(i+.5)}$$

Using the Linear Trapezoidal Method and Riemann Sum approach give roughly the same aggregated emissions for Bulgaria (see Table 12 below).

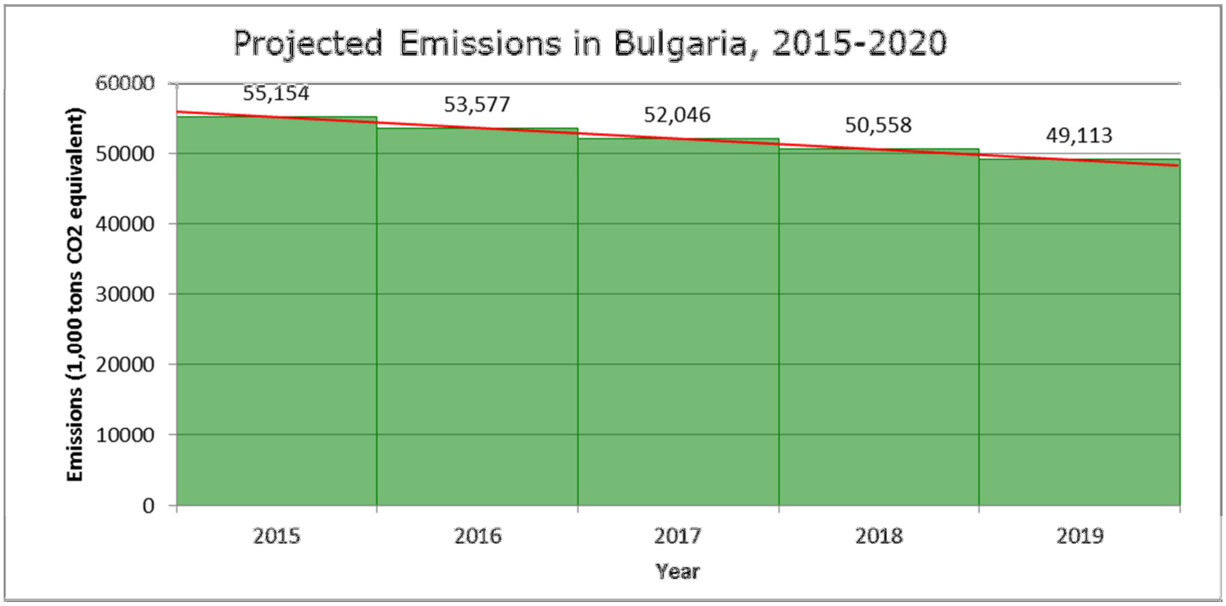
Table 12 – Aggregated Emissions between 2015 and 2020 Using Trapezoidal Method and Riemann Sum

Year (reference year 0 - 2012)	*Total Projected Emissions Each Year*	*Midpoint Height Using Linear Trapezoidal Method (=(B5+B6)/2)*	*Midpoint Height Using Riemann Sum (= 61045.626*EXP(-0.029*(A5+0.5)))*	*Width (Δx)*
0	61045.626			
1	59300.72618			
2	57605.70177			
3	55959.12714			1
4	54359.61744	55159.37229	55153.57417	1
5	52805.82739	53582.72242	53577.09003	1
6	51296.45014	52051.13877	52045.66737	1
7	49830.21624	50563.33319	50558.01819	1
8	48405.89248	49118.05436	49112.89128	1
Total Emissions 2015-2020		260474.621	260447.241	

Source: Own Table

Here we can see what this visualization of Riemann sums to calculate aggregate emissions between 2015 and 2020 looks like, with Equation (5) used to forecast emissions indicated by the red line.

Figure 13 – Visualization of Calculation of Projected Emissions in Bulgaria Using Riemann Sums



Source: Own Figure

We can also find the definite integral for Equation 9 between *a* and *b,* of which a=3 (2015) and b=8 (2020) since our base year 0 would be the reference year (2012). The area under the curve as described this equation would be in the form of

Equation 8 – Definite Integral for Finding Total Emissions

$$\int_a^b f(x)dx = \lim_{n\to\infty} \sum_{i=1}^{n} f(xi)\Delta x \quad (8)$$

Here, the right side of the equation is the Riemann Sum used above, but where the number of rectangles (denoted by *n)* summed approaches infinity to ensure the highest possible level of accuracy. This can also be done through the use of anti-derivatives and finding the value of the anti-derivative at *b*, and subtracting the value of the anti-derivative at *a,* with capital *F(x)* denoting the anti-derivative of *f(x)*, and appearing as

Equation 9 - Using the Definite Integral to Find Total Emissions in Bulgaria between 2015-2020

$$\int_3^8 f(x)dx = F(8) - F(3)$$

Calculating the anti-derivative of $f(x) = 61{,}045.626e^{-.029x}$ we find

$$\int_3^8 61{,}045.626e^{-.029x}\,dx = \left[-2105021.5862e^{-.029x}\right]_3^8 = F(8) - F(3)$$

$$F(8) - F(3) = 260{,}456\ KtCO2\ Eq.$$

While very close to the value calculated using the Riemann Sum method, this value is the exact amount of emissions forecasted in Bulgaria for the years between 2015 and 2020. For the purposes of policy development it seems reasonable to use either estimation method for this calculation.

2. Carbon Abatement Cost Models

Having established greenhouse gas emissions projects for Bulgaria for the period from 2015-2020, the task now turns to determining how much of this total can be prevented at low or negative cost. This can be investigated using cost abatement models, two types of which are deployed here. The bottom-up McKinsey model looks at individual abatement options, both in terms of cost and in terms of potential abatement opportunity, in order to arrive at an overall picture of the costs of reducing emissions for economies as a whole. One of the main results of investigating abatement costs in this way is that individual negative or zero cost options for abatement can be specifically identified and pursued by public or private interventions. On the other hand, the top-down models result from the development of cost functions which model abatement costs based on the amount of money that it would cost as a percentage of GDP to reduce the emissions vis-à-vis a business as usual scenario, without looking at individual abatement options.

2.1 Climate and Regional Economics of Development (CRED) Model

Perhaps the most intriguing facet of the McKinsey cost abatement model is that it concludes that some carbon abatement costs are negative.[69] Among some economists, this finding has been somewhat contentious as, on its face, it seems to defy thinking that the capture of economic value by rational economic actors happens under conditions when markets are relatively free.[70] In this vein, other hidden costs and informational deficiencies are not (and cannot be) considered under the McKinsey model. Prominent thinkers have popularized this line of thinking, which has sparked debates about the possibility of negative abatement interventions and the reasons why the McKinsey study has arrived at this conclusion. Others have responded to these criticisms to defend the conclusions of the study.[71][72][73][74]

The McKinsey global abatement cost curve visualizes these individual options at the global level, and we can see that by 2030, 11 GtCO2e per year could be prevented

[69] McKinsey & Company. (2009). Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve. <http://globalghgcostcurve.bymckinsey.com>, Retrieved on 19.8.2012

[70] http://www.brookings.edu/blogs/up-front/posts/2009/12/30-negative-costs-gayer Retrieved on: 21.8.2012

[71] Delong, Brad, Blog <http://delong.typepad.com/sdj/2009/12/the-brookings-institution-needs-to-exercise-some-quality-control.html > Retrieved 21.8.2012.

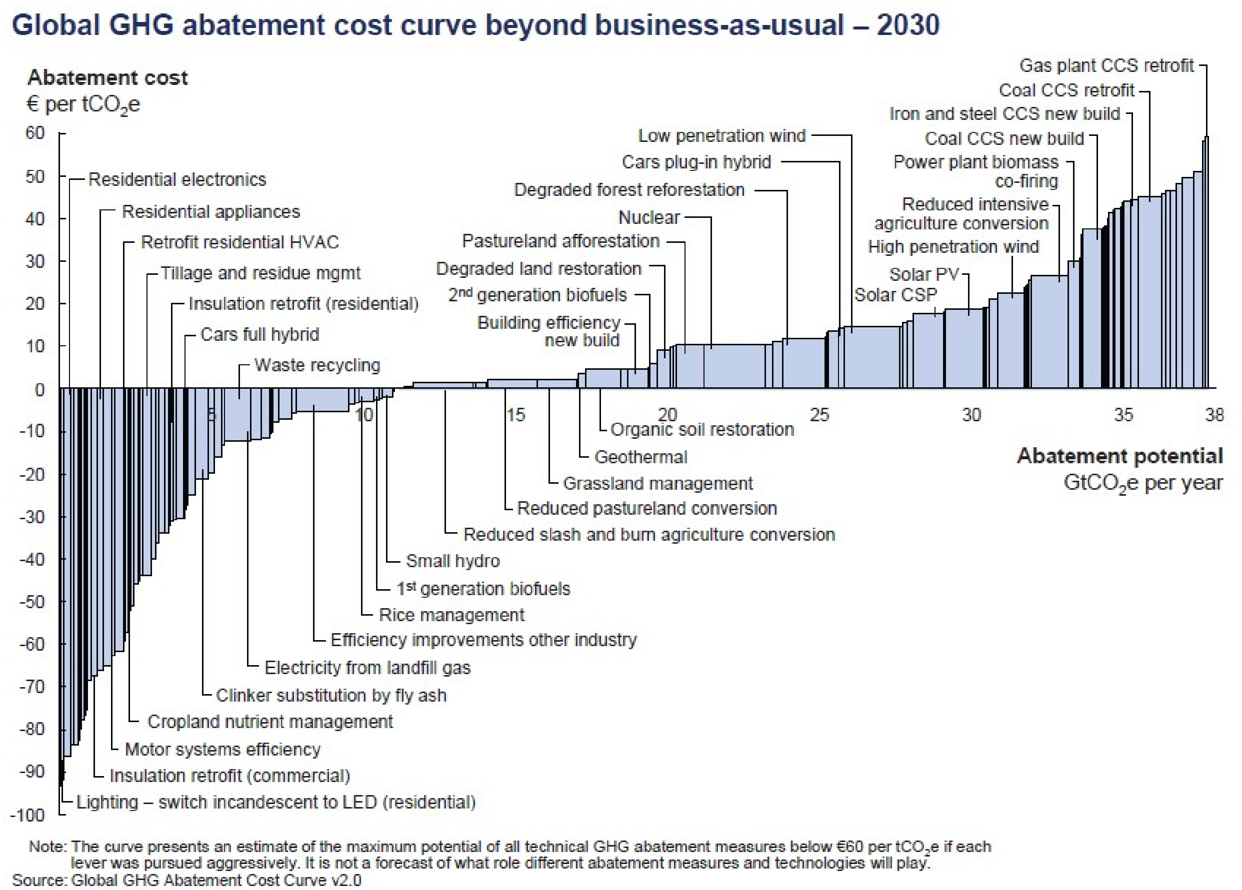
[72] Krugman, Paul, New York Times Blog, <http://krugman.blogs.nytimes.com/2009/12/29/energy-gaps/ >, Retrieved 21.8.2012

[73] Avent, Ryan, The Economist, Dec, 29th 2009, Pick Up Those Bills <http://www.economist.com/blogs/freeexchange/2009/12/pick_up_those_bills > Retrieved 21.8.2012

[74] Klein, Ezra, The Washington Post, Theory meets reality; wins <http://voices.washingtonpost.com/ezra-klein/2009/12/theory_meets_reality_wins.html >, Retrieved 21.8.2012

at negative cost globally, and about 38 GtCO2e could be prevented in total for individual abatements under €60 per tCO_2e:[75]

Figure 14 - McKinsey Abatement Cost Curve



Source: McKinsey & Company. (2009). Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve.

In order to understand how this model can be deployed to understand the potential for insulation retrofitting in residential buildings in Bulgaria, we must better understand how this model works.

Firstly, the McKinsey bottom-up approach that was arrived at through a huge dataset and has been simplified though model equations developed by Ackerman,

[75] McKinsey & Company. (2009). Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve. <http://globalghgcostcurve.bymckinsey.com>, Retrieved on 19.8.2012

Stanton and Bueno to transmute it into a top-down model that allows it to be more easily deployed in other applications.[76] The equation is presented in the form of

Equation 10 – CRED Two-Parameter Marginal Cost Function

$$z' = A\frac{R}{B-R} \qquad (9)$$

Where z' is the marginal cost per unit of carbon dioxide at a particular abatement level, R is the amount of the reduction, B is the amount of reduction where marginal cost turns infinite and A is the cost parameter. Parameters for A and B are given by Cline in Table 13.

Table 13 – Abatement Cost Parameters for CRED Two-Parameter

Country	Parameter A (billions of 2005 dollars)	Parameter B (GtC)
Argentina	*51.53*	*.04*
Australia	*107.41*	*.09*
Brazil	*51.53*	*.08*
Canada	*107.41*	*.13*
China	*66.39*	*2.64*
Egypt	*64.5*	*.04*
European Union	*101.41*	*.76*
India	*53.9*	*.52*
Indonesia	*53.9*	*.12*
Iran	*46.53*	*.12*
Japan	*107.41*	*.3*
Kazakhstan	*36.8*	*.05*
Malaysia	*53.9*	*.07*
Mexico	*51.53*	*.1*
Pakistan	*53.9*	*.05*
Russia	*36.8*	*.38*
Saudi Arabia	*46.53*	*.1*
South Africa	*64.5*	*.11*
South Korea	*53.9*	*.16*
Taiwan	*53.9*	*.09*
Thailand	*53.9*	*.09*
Turkey	*101.91*	*.05*
Ukraine	*36.8*	*.08*
United States	*64.74*	*1.39*
Venezuela	*51.53*	*.04*
Rest of World Industrial	*107.41*	*.12*

Source: Own Table

[76] Ackerman, Frank, Elizabeth Stanton, and Ramon Bueno. 2010. CRED: A New Model of Climate and Development. Stockholm Environment Institute Working Paper WP-US-10-03 (April). Somerville, MA: Stockholm Environment Institute.

It is important to note that this approach removes the negative marginal cost possibilities of the McKinsey study estimates and instead represents negative costs as zero or near zero.[77]

Equation (9) must be integrated between zero and the desired cutback R in order to find the area under the curve that represents the total cost of abatement. This comes in the form of:

Equation 11 – Total Abatement Cost Equation CRED Two-Parameter

$$z = \int_0^R z' = A[B \ln \frac{B}{B-R}] - R \qquad (10)$$

By using this equation, and the values for A and B, it is possible to approximate the cost of any level of abatement which is below Parameter B (the upper limit of abatement where cost turns infinite) and allow a calculation for the amount of abatement that is available at various price points. Using the data from Table 13 above, we can see that for Parameter A (which is the marginal cost at half of the total possible emissions, or where *R=B/2*) a figure of 36.8 billion USD in 2005 is used for Kazakhstan, Russia and Ukraine, which are part of the Eastern European and Central Asian (ECA) region, along with Bulgaria.

For the purposes of this model, it is seen as infinitely expensive and thus theoretically impossible to eliminate all greenhouse gas emissions. This concept helps to integrate economic realities and technological and physical hurdles into the equation, given that some parts of the economy do not yet have cheap and efficient enough technology to reduce emissions cheaply after low-cost emissions abatements have been captured. In order to understand how much it will cost to abate carbon at various levels, and how much can reasonably be abated, the proportion of total emissions at which this cost turns infinite in Bulgaria is calculated below.

This is first determined by assessing the percentage of total emissions where costs for abatement turn infinite within the ECA region.

[77] Cline, William R. (2011). Carbon Abatement Costs and Climate Change Finance. Peterson Institute for International Economics. Washington D.C. U.S.A. p 30.

Table 14 - Feasible Abatement Amount - Bulgaria

	Parameter A	Parameter B (GtC)	GtCO2	Projected 2020 GtCO2 (Cline)	%
Kazakhstan	*36.8*	*0.05*	*0.1835*	*0.236*	*0.777542*
Russia	*36.8*	*0.38*	*1.3946*	*1.8*	*0.774778*
Ukraine	*36.8*	*0.08*	*0.2936*	*0.389*	*0.754756*
					Average Percentage of Total Emissions Where Cost Turns Infinite
					0.769025333
Bulgaria	*36.8*	*0.01*	*0.03726*		

Source: Own Table

The parameters for *B*, for the three countries in the ECA region, are given as calculated by Cline for 2020 in GtC. These figures were then multiplied by 3.67 (the conversion constant for converting GtC of carbon to $GtCO_2$) to arrive at figures for $GtC0_2$.[78] These figures were then divided by the projected $GtCO_2$ figures for these countries in 2020 in order to determine the percentage at of total emissions at which costs turn infinite. These percentages were then averaged and were determined to be approximately 77%.

Thus, the approximate point at which abatement costs turned infinite was determined to be just less than 77% of total emissions. This figure was applied to the projected $GtCO_2$ emissions level of Bulgaria in 2020 calculated above 48,406 Gt CO_2e, to find the maximum possible abatement of 37.27 Gt CO_2e. It was then divided by the conversion coefficient of 3.67 from GtCO2 to GtC to find *Parameter* B for Bulgaria of .01 GtC.[79]

The CRED Two-Parameter Equation populated with Parameters *A* and Parameters *B* for Bulgaria is thus:

Equation 12 - CRED Two-Parameter Marginal Cost Function (Populated)

$$z' = 36.8\frac{R}{.01-R}$$

[78]Dessler, Professor Andrew. Introduction to Modern Climate Change, Cambridge University Press, October 10, 2011.

[79] It would have clearly been preferable to have disaggregated values for 2020 instead of 2030, considering that the maximum possible abatement by 2020 will likely be lower considering the increased time constraint and also to have these values for Bulgaria itself.

Where *z′* equals the marginal abatement cost in billions US$ per Gt of carbon and *R* is the amount of the reduction.

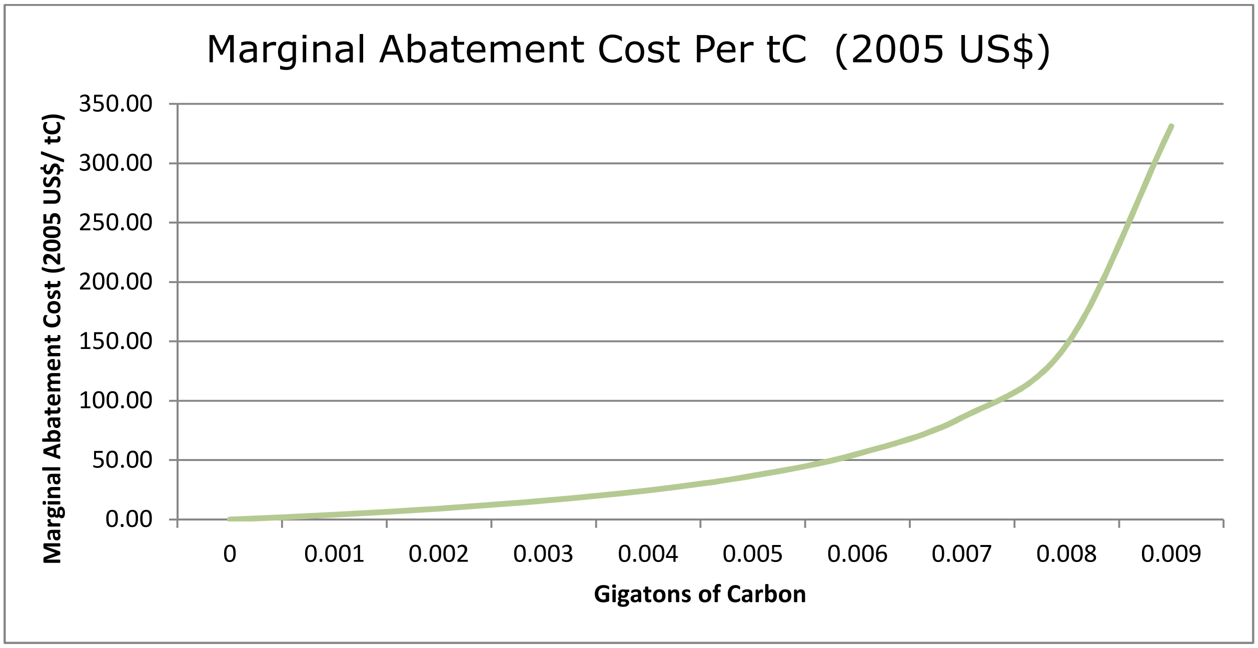
Table 15 - Marginal Abatement Cost Billions US$/GtC

At this abatement level in GtC (R)	At his abatement level in GtCO2	Marginal Abatement Cost (Billions 2005 US$ per GtC)
0	*0*	*0.00*
0.001	*0.00367*	*4.09*
0.002	*0.00734*	*9.20*
0.003	*0.01101*	*15.77*
0.004	*0.01468*	*24.53*
0.005	*0.01835*	*36.80*
0.006	*0.02202*	*55.20*
0.007	*0.02569*	*85.87*
0.008	*0.02936*	*147.20*
0.009	*0.03303*	*331.20*
0.01	*0.03726*	*3643.20*

Source: Own Table

Note that the marginal abatement cost is 36.8 where half of all theoretically possible abatement occurs this is Parameter A. The marginal abatement costs are in billions of 2005 USD per Gt of carbon. Since these figures are somewhat non-intuitive due to the fact that nothing close to a Gt of carbon is emitted in Bulgaria, and since the units can cancel between billions of USD and GtC (billions of tons of carbon), the right column is better viewed as the cost in dollars to abate one ton of carbon at the various abatement levels. This data are visualised for more ready comprehension in Figure 15, where we can see the increasing marginal costs of abating carbon as we approach the upper limit for Bulgaria. For example, after .006 Gt (6,000,000 tC) of carbon has been abated, each ton of carbon abated costs 55.20 USD per ton to abate.

Figure 15 - Marginal Abatement Cost Curve Based



Source: Own Figure

While the previous table has helped us to understand the costs for one ton of carbon abatement at various abatement levels, it is important from a policy perspective to see the cumulative costs of abatement at various levels. This is using the integrated marginal abatement cost function, in order to measure the total costs incurred for various cutback levels (i.e. the area under the curve):

Equation 13 – Total Abatement Cost Equation Populated

$$z = \int_0^R z' = 36.8[.01 \ln \frac{.01}{.01-R}] - R$$

Where *z* is the cumulative abatement cost in billions of 2005 US$ between 0 and *R* where *R* is the total amount of the reduction. The cumulative abatement levels below are values which are calculated are the actual costs of achieving various abatement levels in Bulgaria according to the model.

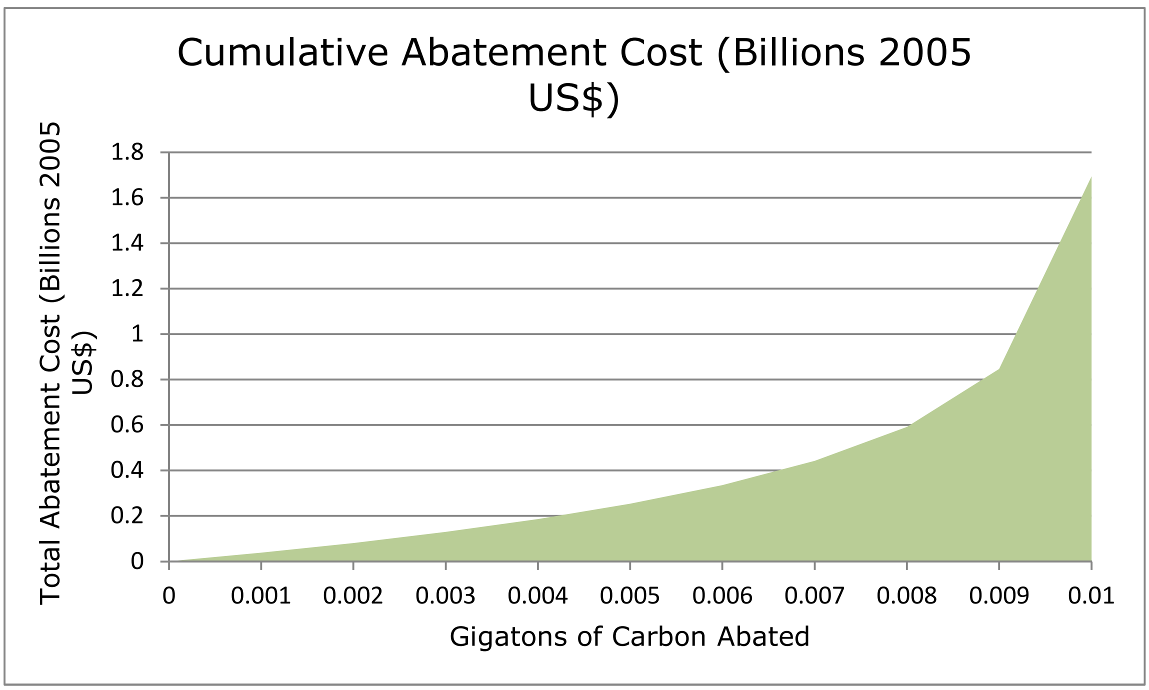
Table 16- Total Abatement Costs at Various Abatement Levels

At this abatement level in GtC (R)	At his abatement level in GtCO2	Total Abatement Cost (Billions 2005 US$)
0	*0*	*0.00*
0.001	*0.00367*	*0.04*
0.002	*0.00734*	*0.08*
0.003	*0.01101*	*0.13*
0.004	*0.01468*	*0.19*
0.005	*0.01835*	*0.25*
0.006	*0.02202*	*0.34*
0.007	*0.02569*	*0.44*
0.008	*0.02936*	*0.59*
0.009	*0.03303*	*0.85*
0.01	*0.03726*	*1.69*

Source: Own Table

This data is visualised in Figure 16.

Figure 16 - Cumulative Abatement Costs – Bulgaria



Source: Own Figure

In Figure 16, we can view the ever increasing costs of abatement as the theoretical maximum is approached. In order to compare the costs as a percentage of GDP, we use the International Monetary Fund's estimate of Bulgarian GDP in 2020, which was found to be 74.128 billion USD in constant prices with a base year of 2005 - as does the calculation for Parameter *A* above.[80] When we do this, we see that, for example, abating half of theoretically possible emissions would require about .34% of GDP in 2020 or $250 million 2005 dollars.

Table 17 – Total Abatement Costs as a Percentage of GDP, CRED Two-Parameter Model

At this abatement level in GtC (R)	Total Abatement Cost (Billions 2005 US$)	Total Abatement Cost as a Percentage of GDP in 2020
0	*0.00*	*0.00%*
0.001	*0.04*	*0.05%*
0.002	*0.08*	*0.11%*
0.003	*0.13*	*0.18%*
0.004	*0.19*	*0.25%*
0.005	*0.25*	*0.34%*
0.006	*0.34*	*0.45%*
0.007	*0.44*	*0.60%*
0.008	*0.59*	*0.80%*
0.009	*0.85*	*1.14%*
0.01	*1.69*	*2.29%*

Source: Own Table

2.2 Nordhaus Regional Dynamic Integrated Model of Climate and the Economy (RICE) Model

Given that there are various assumptions taken within these models, we would like to deploy more than one in order to bolster confidence these forecasts. As such, we also investigate costs using the RICE model, developed by William Nordhaus, and which aims to calculate the costs of undertaking carbon abatements based on the following formula:

Equation 14 - Abatement Equation RICE

$$Kt = \alpha_t \mu_t^{\beta} \tag{11}$$

[80] *International Monetary Fund, World Economic Outlook Database, October 2014. Accessed on January 4th, 2015.*

Where *K* is the cost as a fraction of GDP, α is a parameter the declines over time to reflect increasing technological (and therefore cheaper) abatement options, μ is the percentage reduction in emissions from business-as-usual, β is an exponent showing the rate at which costs for abatement cuts increase (here held to be constant at 2.8), and *t* reflects the year in question.

Nordhaus has calculated the cost parameter variables for a number of countries and regions as displayed in the following table:[81]

Table 18 - Abatement Cost Parameter (α) RICE

Country/Region	2020	2030	2040	2050
United States	.036	.029	.024	.020
European Union	.034	.028	.024	.021
Japan	.047	.039	.032	.027
Russia	.044	.036	.030	.025
Eurasia	.049	.038	.030	.024
China	.063	.049	.038	.030
India	.066	.052	.042	.034
Middle East	.055	.045	.037	.031
Africa	.042	.033	.026	.021
Latin America	.038	.032	.027	.023
Other High Income	.048	.039	.032	.027
Other non-OECD Asia	.070	.057	.046	.039

Source: Own Table

An example of this model in action would be to calculate the percentage of GDP that it would take China to reduce greenhouse gases by 50% by 2020 as well as the cost of doing this by 2050.

For the 2020 calculation, $k = .063 \times .5^{2.8} = .0090 = .9$ *% of GDP*
For the 2050 calculation, $k = .03 \times .5^{2.8} = .0043 = .43$ *% of GDP*

We can see from these calculations that the costs of reducing emissions get higher the sooner that the reduction deadline is. It also illustrates the importance of early action in reducing overall costs. Using the formula above and the 2020 figure of .034 for the European Union as a proxy for Bulgaria, we get the following results.

[81] These figures are derived from the IPCC Fourth Assessment Report as well as the Energy Modeling Forum 22 Report.

Table 19 - Abatement Cost in Bulgaria as a Percentage of GDP at Various Cutback Levels – NORDHAUS RICE Model

At this abatement level in GtC	At his abatement level in GtCO2	Percentage Carbon Reduction from Business as Usual	Cost as a Percentage of GDP - RICE
0	*0*	*0.00000%*	*0.00%*
0.001	*0.00367*	*7.56763%*	*0.00%*
0.002	*0.00734*	*15.13527%*	*0.02%*
0.003	*0.01101*	*22.70290%*	*0.05%*
0.004	*0.01468*	*30.27054%*	*0.12%*
0.005	*0.01835*	*37.83817%*	*0.22%*
0.006	*0.02202*	*45.40581%*	*0.37%*
0.007	*0.02569*	*52.97344%*	*0.57%*
0.008	*0.02936*	*60.54108%*	*0.83%*
0.009	*0.03303*	*68.10871%*	*1.16%*
0.01	*0.03726*	*74.91958%*	*1.51%*
0.011	*0.04037*	*83.24398%*	*2.03%*
0.012	*0.04404*	*90.81161%*	*2.60%*
0.013	*0.04771*	*98.37925%*	*3.25%*
0.013214169	*0.048496*	*100.00000%*	*3.40%*

Source: Own Table

Even though the upper limit for feasible abatement is .01 GtC, we have calculated values up to the total Business As Usual carbon emissions scenario in 2020 to illustrate the costs predicted by these models for mitigating 100% of emissions. These appear lower than the costs for the CRED Two-Parameter model until about .0075 Gt is abated, and when graphed, show somewhat similarly shaped curves (see Figure 17 below). Thus, we can say that the Nordhaus RICE model has lower cost estimations for initial emissions reductions than does the CRED Two-Parameter Model.

2.3 EMF-22 Model

The EMF-22 model uses the same equation logic as does the Nordhaus RICE model, being

Equation 15 - Equation EMF-22 Model

$$Kt = \alpha_t \mu_t^{\beta} \tag{12}$$

However, the values for α and β differ quite substantially based on different assumptions and calculation logics. Where K is the cost as a fraction of GDP, α is a parameter the declines over time to reflect increasing technological (and therefore cheaper) abatement options, μ is the percentage reduction in emissions from business-as-usual, β is an exponent showing the rate at which costs for abatement cuts increase (which unlike RICE change over time), and t reflects the year in question.

The following table from Cline describes these values for α and β:

Table 20 - Abatement Parameters EMF-22

Country	2020	2030	2040	2050
α				
China	.087	.087	.1	.078
European Union	.025	.025	.024	.024
India	.090	.090	.066	.066
United States	.049	.049	.023	.023
Group 1	.031	.031	.030	.021
Group 2	.101	.101	.073	.073
Group 3	.092	.092	.102	
β				
China	1.381	1.381	1.586	1.586
European Union	1.278	1.278	1.442	1.442
India	1.545	1.545	1.412	1.412
United States	1.569	1.569	1.158	1.158
Group 1	1.457	1.457	1.612	1.612
Group 2	1.532	.1532	1.336	1.336
Group 3	1.413	1.413	.1764	1.764

Source: Own Table

Again, calculating the cost of halving emissions, as a percentage of GDP for China in 2020 and 2050, we see the following:

For the 2020 calculation, $k = .087 \times .5^{1.381} = .0334 = 3.34\ \%$ *of GDP*
For the 2050 calculation, $k = .078 \times .5^{1.586} = .0259 = 2.59\ \%$ *of GDP*

In order to construct cost calculation as a percentage of GDP, the 'Group 1' values were used as they defined as the values for the Annex 1 Parties to the United Nations Framework Convention on Climate Change, of which Bulgaria is one. Thus, our α value for this formula will be .031 and our β will be 1.457.

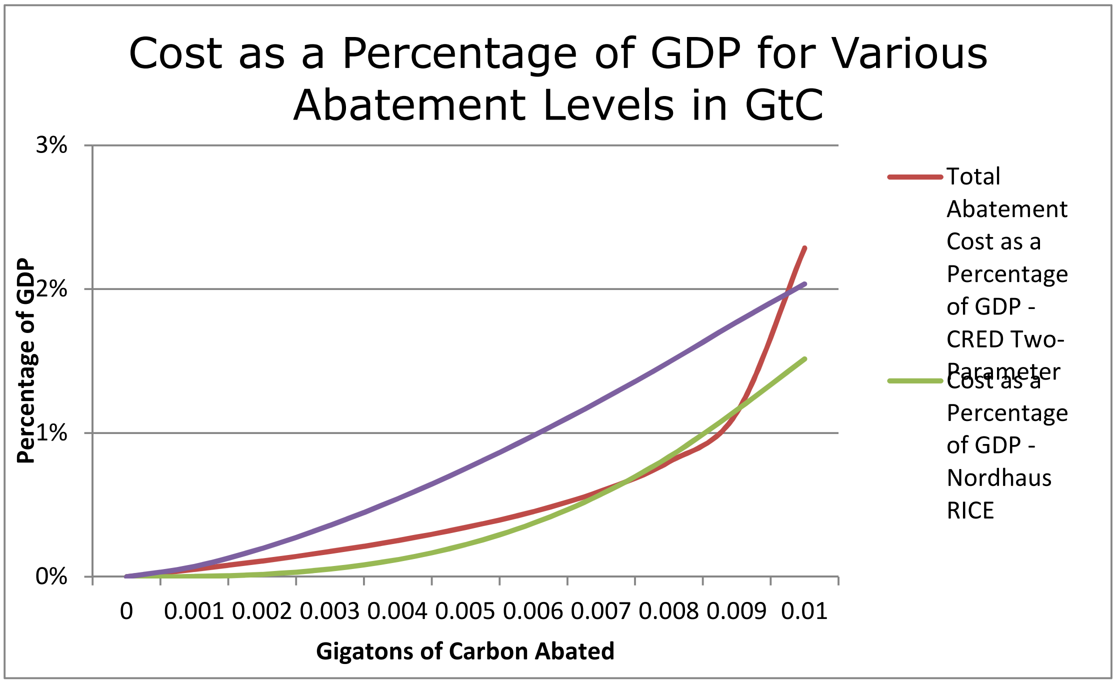
Table 21 - Abatement Cost in Bulgaria as a Percentage of GDP EMF-22 at Various Abatement Levels

At this abatement level in GtC	At his abatement level in GtCO2	Percentage Carbon Reduction from Business as Usual	Cost as a Percentage of GDP - EMF-22
0	*0*	*0.00000%*	*0.00%*
0.001	*0.00367*	*7.56763%*	*0.07%*
0.002	*0.00734*	*15.13527%*	*0.20%*
0.003	*0.01101*	*22.70290%*	*0.36%*
0.004	*0.01468*	*30.27054%*	*0.54%*
0.005	*0.01835*	*37.83817%*	*0.75%*
0.006	*0.02202*	*45.40581%*	*0.98%*
0.007	*0.02569*	*52.97344%*	*1.23%*
0.008	*0.02936*	*60.54108%*	*1.49%*
0.009	*0.03303*	*68.10871%*	*1.77%*
0.01	*0.03726*	*74.91958%*	*2.04%*
0.011	*0.04037*	*83.24398%*	*2.37%*
0.012	*0.04404*	*90.81161%*	*2.69%*
0.013	*0.04771*	*98.37925%*	*3.03%*
0.013214169	*0.048496*	*100.00000%*	*3.10%*

Source: Own Table

As can be seen in Figure 17, the cutback from baseline using this model is higher for initial emissions cutbacks than the other two models and converges with the CRED Two-Variable Model as it approaches a cutback of .01 Gt. It should be noted that since while the Nordhaus-Rice and EMF-22 Models also show that costs increase as emissions reductions increase, they do not have an inherent upper limit where cost turns infinite as with the CRED Two-Parameter Model – which explains why this model increases aggressively as it approaches this upper limit.

Figure 17 - GDP Needed to Achieve Difference Abatement Levels Using the Three Models



Source: Own Figure

III. Calculating Abatement Costs for Basic Building Envelope Retrofits

Bottom-Up Building Retrofit Calculations for McKinsey Model

While the previous top-down approaches illuminate the low costs involved in initial emissions reductions, they do not, by design, consider the potential of negative cost abatement options to reduce emissions levels. Energy efficiency options are a particularly important area for such emissions reductions. According to the *McKinsey Greenhouse Gas Abatement Cost Curve,* many energy efficiency improvements, such as building envelope retrofits in residential buildings, can contribute to significant reductions in global emissions and can be done at a net negative cost.

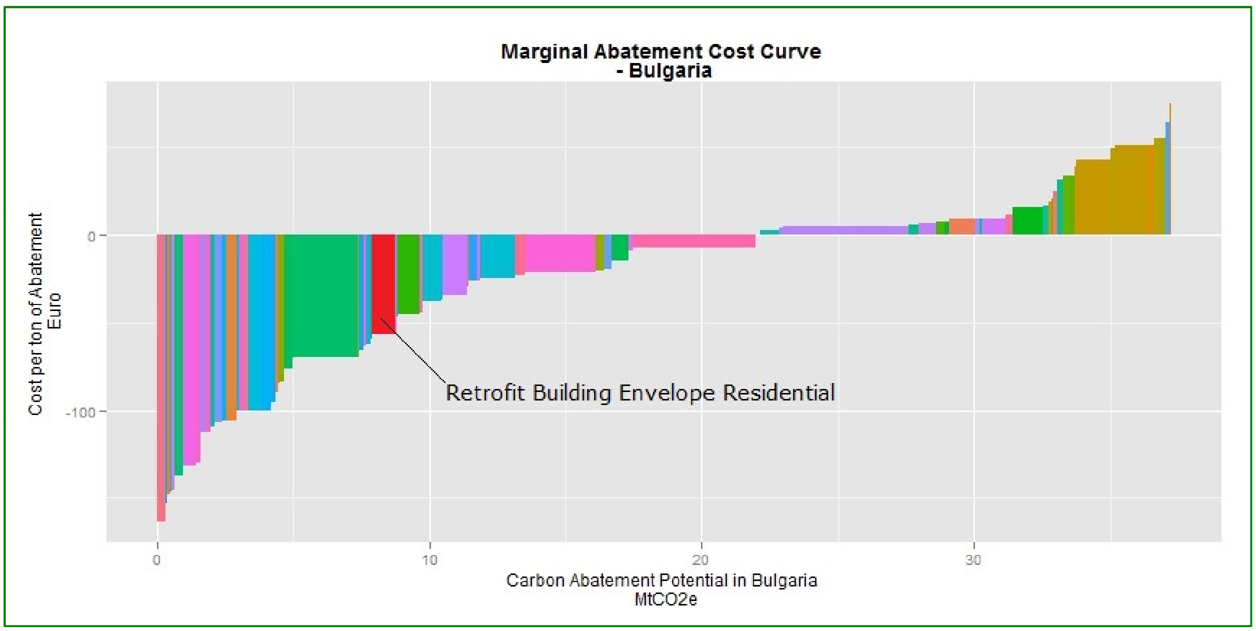
The McKinsey Cost Curve has identified technical opportunities that are available to reduce greenhouse gases, do not negatively affect quality of life, and which are nearly all under €60 (2005) per ton of CO_2e abated. The width of each column in the cost curve represents the potential of a particular action to reduce emissions in a specific year compared to a business-as-usual scenario. This reduction potential assumes that action to capture each opportunity started in 2010. The height of each column represents the average cost of preventing one ton of CO_2e from being emitted by 2020 through each abatement opportunity. The cost is an average of the sub-opportunities within each opportunity. McKinsey makes it clear that "the curve should be used for overall comparisons of the size and cost of different opportunities, the relative importance of different sectors and regions, and the overall size of the emission reduction opportunity, rather than for predictions of the development of individual technologies."[82] They also note that the cost curve cannot be used as a sole source for decision-making as to how policy should be designed and how public money should be allocated, since methods to pay the up-front costs of the abatements through taxation and their distribution, in the form of subsidies and varying interest rates, are not considered. Nor do the costs of the opportunities include the transaction and program costs to achieve the opportunities, as these are context dependent and happen within the framework of local political and administrative structures.

[82] McKinsey & Company. (2009). Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve. <http://globalghgcostcurve.bymckinsey.com>, Retrieved on 19.8.2012

A retrofit of building envelopes in Eastern Europe were estimated by McKinsey for Eastern Europe at -56.87€ preventing one ton of CO_2e (2005 Euros) by 2020.[83] The countries included in the Eastern Europe estimation include Turkey, Albania, Belarus, Bosnia-Herzegovina, Croatia, Gibraltar, FYR of Macedonia, Moldova, Montenegro, and Serbia. Bottom-up calculation logic was used for every possible individual abatement opportunity. The values used to calculate this figure for Eastern Europe are available in Annex 1.

These costs for each abatement opportunity were adapted for the Bulgarian case. Since specific data for Bulgaria was not available within the cost curve, the total abatement potential for Bulgaria for each opportunity was then proportionally scaled down from this group of Eastern European countries (471 Mt CO2e) to the theoretically upper limit of possible emissions in Bulgaria (37.26 Mt CO2e) to calculate the level of emissions that can be abated for each opportunity in Bulgaria by 2020 (see Annex 2 for numeric values and code used to construct the cost curve using the statistical software R). Thus, the cost curve in Figure 18 is a scaled down version of the cost curve for these countries as a group, with the specific abatement possible from retrofits of building envelopes noted.

Figure 18 - Marginal Abatement Cost Curve for Bulgaria for 2020



[83] This "Level 1" retrofit includes: improving building air tightness by sealing baseboards and other areas of air leakage; weather strip doors and windows; insulate attic and wall cavities, add basic mechanical ventilation system to ensure air quality. It is assumed that this will result in a 15-25% heating savings potential and up to 10% cooling savings. The retrofit is based on an estimate of 6.26€ per square meter in Western Europe and Japan and scaled down according to GDP. In Annex 1 it can be seen that the costs in Eastern Europe are estimated at 3.66€ per square meter

Source: Own Table based on the McKinsey Cost Curve for Easter Europe Using R

Using this approach, it was found that .87 $MtCO_2$ could be prevented (from 7.91 MtCO2e to 8.78 MtCO2e) from being emitted in 2020 with a negative cost of -49.48€ million (2005 Euros). According to the model, if all 82 opportunities in the above table were exploited, then all 37.26 of feasibly abatable MtCO2e could be prevented by 2020 (assuming that aggressive action started in 2010) - for a total aggregate cost of -801.01€ million (2005 Euros). Also, according to this model, 22 MtCO2e could be captured for a total cost of -1083.49€ million (2005 Euros).

In order to investigate the costs of abating the same .87 MtCO2 through the other cost abatement models (i.e. CRED model, RICE Model, EMF-22 Model), we now turn to the previously defined equations and superimpose the adapted McKinsey cost curve for Bulgaria over it to see where this opportunity falls on these abatement cost functions.

Climate and Regional Economics of Development (CRED) Model

The CRED model is mobilized by transposing the range of carbon abatement that can be captured through building envelope retrofits onto the CRED Two-Parameter model and calculating the costs incurred. This is done by integrating of the marginal cost equation and finding the definite integral between 7.91 MtCO2e to 8.78 MtCO2e. This is done by calculating the value from 0 to the upper value of carbon abated by building envelope retrofits in GtC (8.78 MtCO2e or .002392684 GtC) and subtracting the integral of the marginal cost equation from 0 to the lower value of carbon abated (7.91 MtCO2e or .002155539 GtC) by building envelope retrofits in GtC using Eq. (10):

Equation 16 - Total Abatement Cost Equation CRED Two-Parameter

$$z = \int_0^R z' = A[B \ln \frac{B}{B-R}] - R$$

Where *z* is the total cost of abatement between 0 and *R*, *R* is the amount of the reduction, *B* is the amount of reduction where marginal cost turns infinite and *A* is the cost parameter. The value for *A* was given by Cline and the parameter for *B* was calculated above such that

$$z = \int_0^R z' = 36.8[.01 \ln \frac{.01}{.01-R}] - R$$

The upper and lower limits for building envelope refurbishment were calculated above as .002392648 GtC to .002155530 GtC respectively such that the value from *0* to *R* would be

$$Z_H = \int_0^R z' = 36.8[.01 \ln \frac{.01}{.01 - .002392648}] - .002392648 = .099967 \; Billion\, USD\; (2005)$$

Where the value from 0 to the lower value can be found by

$$Z_L = \int_0^R z' = 36.8[.01 \ln \frac{.01}{.01 - .002155539}] - .002155539 = .088719 \; Billion\, USD\; (2005)$$

When finding the definite integral then we subtract Z_H from Z_L to find

$$Z_H - Z_L = 11{,}247{,}197 \text{ Million 2005 USD}$$

Using the CRED Two-Parameter Model, and assuming that the McKinsey Model accurately captures all possible carbon abatement options, it would cost 11.2 million 2005 USD to abate the same .87 MtCO2 of carbon that was done at negative cost using the McKinsey bottom-up model.

Nordhaus Regional Dynamic Integrated Model of Climate and the Economy (RICE) Model

We use Eq. (11) in this instance

Equation 17 - Abatement Equation RICE

$$Kt = \alpha_t \mu_t^{\beta}$$

Where *K* is the cost as a percentage of GDP, α is a parameter the declines over time to reflect increasing technological (and therefore cheaper) abatement options, μ is the percentage reduction in emissions from business-as-usual, β is an exponent showing the rate at which costs for abatement cuts increase (here held to be constant at 2.8), and *t* reflects the year in question. Here, α is equal to .034, μ is .181 (the upper percentage of carbon reduction from BAU – see Annex 3 for calculation) and β is 2.8.

$$K_H = .034_t \, .181_t^{2.8} = .0284\%$$

When we use the same equation for the lower percentage of carbon reduction from BAU, we find:

$$K_L = .034_t\ .163_t^{2.8} = .0212\%$$

Subtracting these two percentages, we find a total cost as a percentage of GDP of .0072%. The International Monetary Fund projects that total GDP in Bulgaria will be 74.128 billion USD in 2020. Multiplying the cost as a percentage of GDP to the total GDP in 2020, we find an opportunity cost to the economy of $5,335,913.71 (2005 dollars) in 2020 to abate this carbon.[84]

EMF-22 Model

This same calculation logic holds for the EMF-22 Model, except with different figures for α (.031) and β (1.457) using Eq. (12).

Equation 18 – Abatement Equation EMF-22

$$Kt = \alpha_t \mu_t^{\beta}$$

$$Kh = .031_t\ .181_t^{1.457} = \ .2571\%$$

When we use the same equation for the lower percentage of carbon reduction from BAU, we find:

$$Kl = .031_t\ .163_t^{1.457} = \ .2208\%$$

Subtracting these two percentages, we find a total cost as a percentage of GDP of .0363%. The International Monetary Fund projects that the GDP in Bulgaria will be $74.128 billion USD 2005 dollars, indicating that this abatement opportunity would have an opportunity cost to the economy of $26,879,744.66 (2005 dollars) in 2020. Taking all of the abatement calculations together we see the following

Table 22 - Cost Estimations Using Four Models

McKinsey Bottom-Up Approach	CRED Model	RICE Model	EMF-22 Model
-49.48€ million (2005 Euros)	$11,247,197 2005 USD	$5.335,913.71 2005 USD	$26,879,744.66 2005 USD

Source: Own Table

While the figures are given in two different currencies since the McKinsey study uses euros, they are near zero relative to the total funding that any national government would likely have to implement such improvements. As such, it was not seen as necessary to convert them into the same currency and use the same

[84] International Monetary Fund, World Economic Outlook Database. Available at: http://www.imf.org/external/pubs/ft/weo/2014/02/weodata/index.aspx

calculation logic so as to illustrate this point. Of course, it must be borne in mind that such calculations for the CRED, RICE and EMF-22 Model will only hold true if all abatement opportunities calculated by McKinsey are properly captured, and the relative costs of each opportunity compared to the others are ordered properly from lowest to highest on the McKinsey cost curve. If this is true, than indeed the costs of abatement to economic system as a whole are negligible or negative according to these models. How these benefits are distributed among various societal actors (the private sector, public sector, or individuals) is unclear and does not consider rebound effects nor the specific costs involved in the development and deployment of public programmes to support such renovations.

Information from Bulgaria's National Statistical Institute shows that by the end of 2013 there was 286,416,690 m^2 of useful floor space in dwellings in Bulgaria.[85] According to the Bulgarian Housing Association, as of 2012, the current renovation rate of existing stock is under 1%. Also, since 93.8% of the building stock was built before 1990, we estimate that 92.8% of the total dwelling space desperately needs residential envelope refurbishments – equalling 265,794,688 m^2. Considering the €3.66 per m^2 for the refurbishments listed by McKinsey, total costs in 2005 Euros would be just under one billion Euros (€972,808,558) for this energy efficiency improvement for every residential dwelling in the country – not accounting for the costs benefits to energy savings and improved living quality and economic productivity. Since total receipts from taxes and social contributions in Bulgaria was around €11.5 billion in 2013, this figure of one billion for retrofits constitutes about 11% of the Bulgarian governments operating budget in that year. While significant funds for energy efficiency are earmarked for Bulgaria from European Union sources, this data highlights the fact that innovative models and private sector solutions to capture the value locked within this opportunity are needed.

Total Abated Emissions and Costs from 2015-2020 through Building Envelope Retrofits

The above estimations illustrate the cost involved in abating .87 $MtCO_2$ in 2020. In this study we would like to calculate the aggregated costs between 2015 and 2020, for this abatement opportunity, and the total volume of greenhouse gasses abated between these years. In doing this, we will assume that the growth in emissions reductions is linear (as assumption which is also made in the McKinsey Cost Curve study) based between 2015 and 2020 and resultantly the annual growth in costs. The total emissions abated from basic residential envelope refurbishments, as well

[85] *Republic of Bulgaria, National Statistical Institute* – Useful Floor Space in Dwellings as Of 31.12.2013. Available at: http://www.nsi.bg/en/content/5792/useful-floor-space

as the inherent costs in doing this according to the four abatement models above are presented in Table 22 below

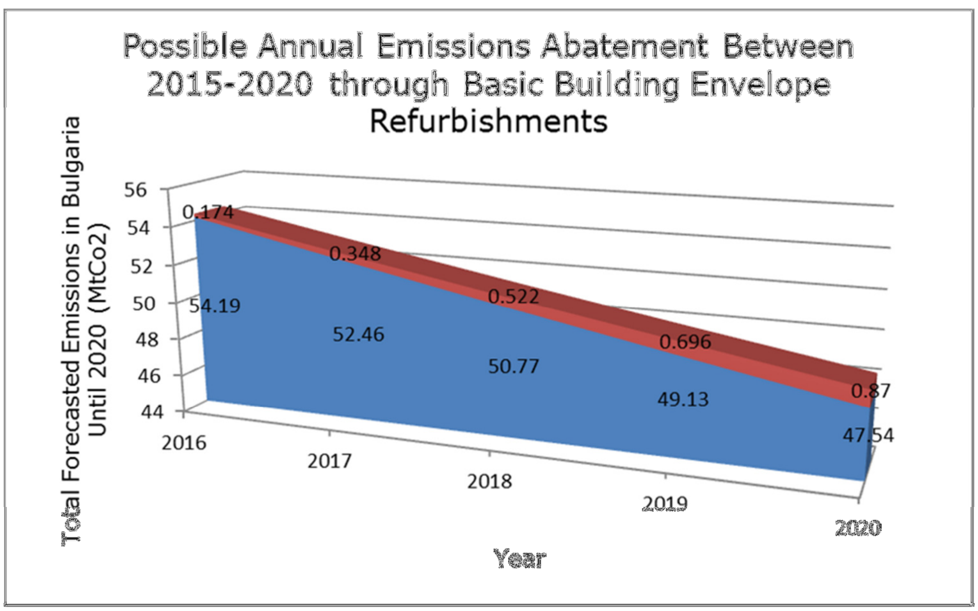
Table 23 - Aggregated Emissions Abated and Aggregated Costs According to Four Cost Abatement Models

Year	*Emissions Abated from Basic Building Envelope Refurbishments (MtCO2)*	*McKinsey Model*	*Climate and Regional Economics of Development (CRED) Model*	*Nordhaus Regional Dynamic Integrated Model of Climate and the Economy (RICE) Model*	*EMF-22 Model*
2015	0.174	-9.896	2.2494	1.067	5.3794
2016	0.348	-19.792	4.4988	2.134	10.7588
2017	0.522	-29.688	6.7482	3.201	16.1382
2018	0.696	-39.584	8.9976	4.268	21.5176
2019	0.87	-49.48	11.247	5.335	26.897
Total 2015-2020	2.61	-148.44	33.741	16.005	80.691

Source: Own Table

We can see that over the five year period, 2.61 $MtCO_2$ can be expected to be abated out of a total of 260.456 $MtCO_2e$ calculated above – almost exactly 1% of emissions from 2015-2020. According to the cost models, this is done at costs ranging from just over -€148 million (in the McKinsey Model) to $80 million in the EMF-22 Model. The piece of total emissions between these years which can be abated through these measures is visualised in Figure 19.

Figure 19 - Forecasted Aggregate Emissions Possible to Abate between 2015 and 2020



Source: Own Figure

These cost abatement models all show very low costs for the initial abatement of emissions. Using the approach taken here, it is seen that building envelope refurbishments have very low or negative costs when factoring in the cost savings that they can deliver. While this appears promising in helping to find economically viable approaches to greenhouse gas abatement, its explanatory power and validity could be improved were real cases of building envelope refurbishments investigated. This paper now turns towards the investigation of some of the possible limiting factors for energy efficiency measures as well as some real-world cases of building envelope refurbishments.

1. The Human Element and Real Case-Based Data for Emissions Prevented and Cost-Savings in Bulgaria

Specific technical estimates regarding the amount of energy and emissions that can be saved by deploying particular energy efficiency improvements may be approximated, but only when a number of assumptions are made. Estimations for the amount of energy needed to power a building before and after an energy efficiency improvement require that the energy consumption of a building be normalized such that calculations for energy consumption presume that the building is being used it was intended to be. For example, if a building is not at full occupancy, real-data for energy consumption must be adjusted to produce a figure of what the building would consume were it at full occupancy given its current characteristics. Then, against this baseline, the predicted consumption following energy efficiency improvements are calculated and the difference is estimated. However, since a building is rarely used under such idealized conditions, estimations for real emissions and energy savings will almost always differ from actual figures.

It is also must be assumed (or factored into estimates, which raises its own new set of issues) that the consumption patterns of residents will remain the same before and after the improvements; a supposition which does not always hold true. The phenomenon of increasingly consumptive behaviours, resulting from cheaper consumption, has been noted by economists for over a century, most famously by William Stanley Jevons. Commonly known as the rebound effect in the economic literature, a particular form of this is known as Jevons Paradox when it is so strong that consumption of a particular resource, following a technological improvement, increases past its level prior to the use of the technology.[86] In Bulgaria, where

[86] Alcott, Blake. *Historical Overview of the Jevons Paradox in the Literature*. In JM Polimeni, K Mayumi, M Giampietro. *The Jevons Paradox and the Myth of Resource Efficiency Improvements*. Earthscan. pp. 7–78.

energy poverty rates, measured as the "inability to keep ones house adequately warm", are over four times higher than the EU average, the possibility for a rebound effect that eliminates at least some of the energy and emissions savings from energy efficiency may indeed exist.

A study by economist Arik Levinson investigates the effects that energy efficiency codes may have on electricity savings in houses in California. He notes a number of generalized phenomena that may explain his conclusion that "there is no evidence that homes constructed since California instituted its building energy codes use less energy today than homes built before the codes came into effect." While spatially bound and focusing on residential homes in California, these phenomena may be relevant in other contexts. In attempting to explain this finding, it is hypothesized that homeowners who want to use more energy services may install energy efficient technologies, or buy more energy efficient homes, which allow them to afford the consumption level that they would prefer, and thus do not *per se* result in energy savings. This selection effect may result in differences between technical estimates of energy consumption and experienced ones. Also, in many calculations of the benefits of energy efficiency, behavioural responses to increased efficiency are not considered, and thus predicted technically possible savings are often exaggerated. Levinson also notes that assessments of *ex-ante* forecasts of energy savings from building codes presume that the codes are enforced properly, (i.e. that the installed improvements are done correctly) or even at all.[87]

In fairness, Levinson's finding only applies directly to the questions of whether building energy codes save energy in Californian homes constructed after the codes came into effect, compared to those constructed prior. Since he found no evidence that this was the case, it was posited that this could be due to home owners retrofitting their older less efficient homes themselves in the interim period (indicating that the retrofits were not caused by policy), and/or due to rebound effects. It is also important to note that even if instituting energy efficiency codes and resultantly increasing energy efficiency does not cause a decrease in energy use, Levinson postulates that this is not necessarily an indictment against energy efficiency. An increase in living qualities though improved indoor environmental conditions is clearly still a desirable societal goal even if it does not address climate change.

In Bulgaria, the fact that the average level of disposable income of homeowners is relatively low may make the possibilities for retrofitting their homes and

[87] Levinson, Arik. *How Much Energy Do Building Energy Codes Really Save? Evidence from California.* Georgetown Economics Department and National Bureau of Economic Research. 2015. Available at: http://www.nber.org/papers/w20797

apartments from their own pockets somewhat less consequential. This results from a lack of ability to afford the up-front costs of improvement, while just barely affording monthly material costs in many cases (i.e. electricity, wood coal, gas etc.). This, coupled with relatively low energy prices, reduces the financial possibility and logic in instituting energy efficiency improvements in residential buildings. The size of the social and political hurdles to incentivizing energy efficiency in the country, such as through instituting a green tax on energy and consumption (as will be seen below) are also immense.

Policies which mandate energy efficiency improvements in residences in Bulgaria would obviously have a different counter-factual scenario than those in California. These differences could make such policies more beneficial in reducing energy consumption and reducing greenhouse gas emissions in Bulgaria, although there is also the possibility that they could have no effect, or even paradoxically increase energy consumption and emissions when compared to their absence. This could be because, in Bulgaria, levels of energy consumption resulting from energy poverty are often below the threshold needed to keep domiciles adequately warm or cool (see Figure 3).

There is an assumption inherent to the energy efficiency calculations that residents are rational actors who make logical decisions that provide them with the greatest benefit, and which are in their own self-interest. In a context of energy poverty, such a rational actor would, if they could afford it, increase their consumption up to a point which provided them the most satisfaction and not more. Consuming more than this amount would, if the theory is to be believed, reduce their satisfaction, as it would prevent them from spending that value on goods and services which brought them more satisfaction. This is what underlies the economic rationality of the rebound effect in that it is economically rational to increase consumption in an environment when that consumption becomes cheaper, if that consumption will increase satisfaction more than using those energy savings on other goods or services.

Some insight into these human elements of energy efficiency can be gleaned when we look at results from the *Parliaments and Civil Society in Technology Assessment (PACITA)* project. This four-year project was funded under the Seventh Framework Programme for Research and Technological Development (FP7).[88] During its implementation, an event was held that deployed the 'World Wide Views' method in order to capture the ideas and opinions of 1026 European citizens from 11 European countries on sustainable consumption.

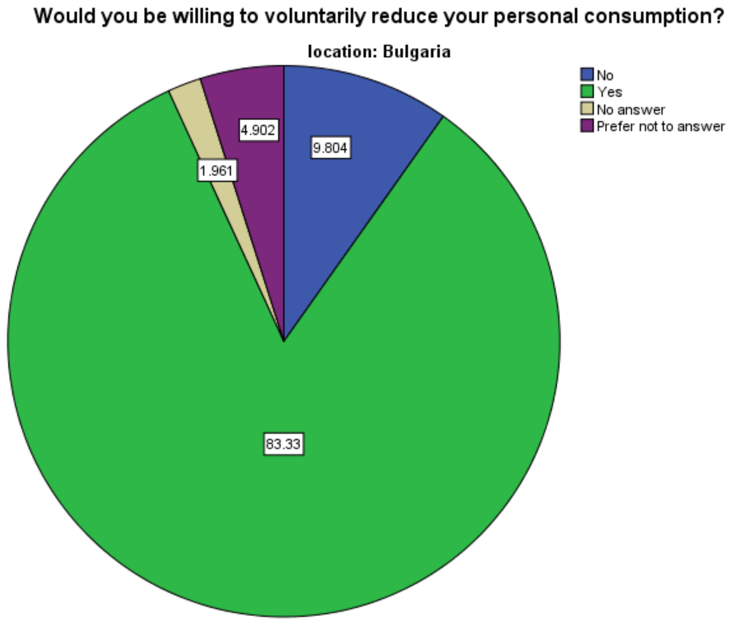
[88] PACITA project website available at: http://www.pacitaproject.eu/

It is not surprising that some evidence from discussions at the World Wide Views event in Bulgaria points to the fact that a significant driver of the low consumption in absolute terms in the country is the inability to afford to consume more.[89] This implies that rising incomes, and making such consumption more affordable through improved efficiency, could make such consumption rebound to a degree that is not entirely clear. If true to any degree, this phenomenon would alter the cost estimates of various emissions abatement levels in models which do not accurately take into account behavioural effects. Relevant results from the data included replies to the question “Would you be willing to voluntarily reduce your personal consumption?” Nearly 10% of Bulgarians (see Figure 20), and 6.5% of all 1,026 respondents (See Figure 21, weighted by country so that generalised conclusions about aggregate citizen values in these countries can be more closely approximated), replied that they would not be willing to voluntarily reduce consumption. While this finding is open to some interpretation, if interpreted literally by respondents and replied to on that basis, the findings allude to the reality that the inherent willingness amongst citizens to consume less should not be assumed. We could arrive at the proposition given these results, that if provided the opportunity to consume less, not all citizens would choose to do so.

We see in Bulgaria that 83.33% of the 102 respondents in Bulgaria indicated that they would be willing to voluntarily reduce consumption, compared to 89.56% of all 1,026 respondents. If taken at face value, there does not seem to be a particularly significant difference in these two sample groups. The more relevant finding for the current study is that this number is unexpectedly further from 100% than the researchers expected. Without any qualification (e.g. if their consumption was already near the basic sustenance level) as to what type of consumption would be voluntarily reduced, a non-negligible number of respondents indicated that they would not voluntarily reduce consumption.

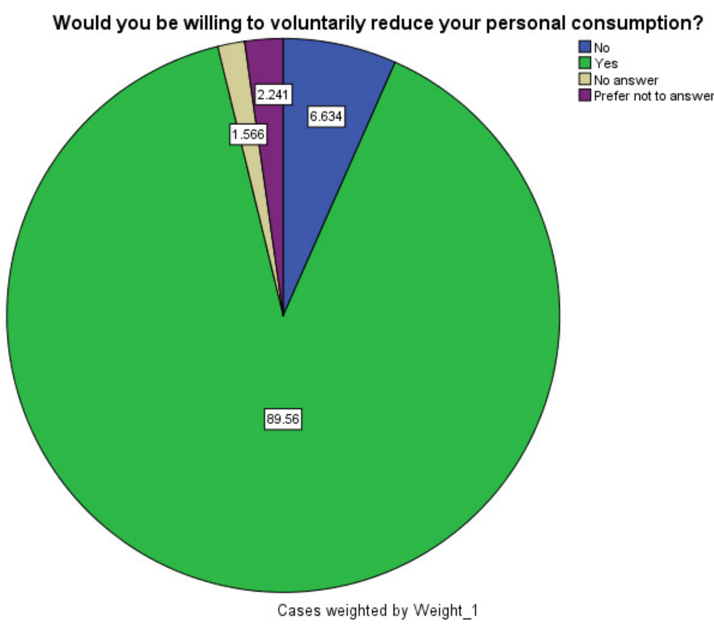
[89] Minutes from the World Wide Views Event, October, 2014, Sofia, Bulgaria

Figure 20 - Responses to question “Would you be willing to voluntarily reduce your personal consumption?” in Bulgaria



Source: Own Figure based on Data from PACITA Questionnaire

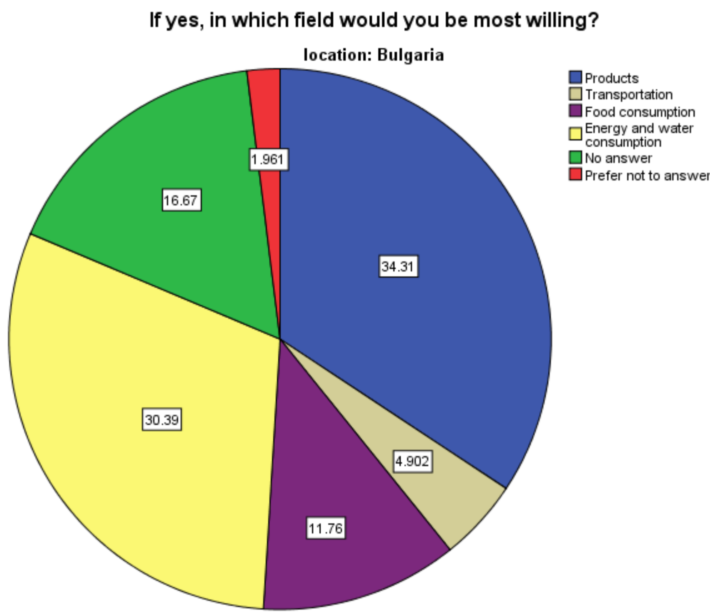
Figure 21 - Responses to question “Would you be willing to voluntarily reduce your personal consumption?” all countries, Weighted



Source: Own Figure based on Data from PACITA Questionnaire

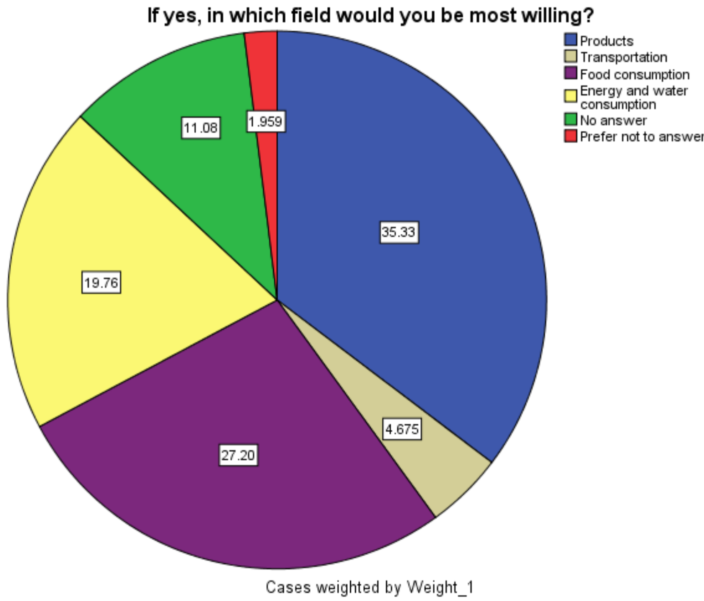
Of those who were willing to voluntarily reduce consumption in Bulgaria, 30.39% (see Figure 22) of respondents were most willing to voluntarily reduce energy and water consumption, compared to 19.76% (See Figure 23 - weighted) amongst the aggregated responses of 1,026 for all countries. The only other significant difference in the response rate between these two groups was for the answer 'food consumption', where 11.76% of Bulgarians choose this answer in comparison to 27.20% (weighted) of respondents from all countries.

Figure 22 - Responses to question "If yes, in which field would you be most willing?" in Bulgaria



Source: Own Figure based on Data from PACITA Questionnaire

Figure 23 - Responses to question "If yes, in which field would you be most willing?" all countries, Weighted



Source: Own Figure based on Data from PACITA Questionnaire

While sampling errors, underlying unidentified characteristics of the participants that do not represent the general population, or the ways that the event was presented and discussions during the event unfolded could all skew the data, we can speculate about the differences is response rates between Bulgaria and the global data for all countries. Energy costs are a particularly charged topic in Bulgaria where allegations of price fixing and malfeasance amongst major suppliers exist and are fuelled by the media. Since such a large percentage of income goes to energy costs in the country, and energy is a relatively inelastic good and electricity provision exists as a natural monopoly, there may be a more visceral desire among many to reduce energy consumption more so than in countries where energy costs are less burdensome as a percentage of income. Since it appears that the differences in the two sample groups result mainly from the relative willingness to prioritize reductions in energy or food consumption and the results are multifactorial, this may also simultaneously result from relatively less real or perceived over-consumption of food in Bulgaria vis-à-vis the sample group encompassing all respondents from all countries.

The impetus for this study is rooted in the intriguing phenomenon that potentially negative or low cost abatement opportunities are not being captured by the market. Of course, the reason that this is intriguing is because of the theoretical assumption that market players are profit-maximizing and rational – and if perfectly profit-maximizing and perfectly rational, all negative cost abatement opportunities would have been captured. However, the validity of this assumption falls apart even under cursory consideration of it, although it does not mean that these opportunities cannot be captured.

This is also exemplified by the results of the survey above which imply that in some cases, people simply do not want to voluntarily consume less even without an explanation of what that might mean (see Figure 21). Also, individuals have different priorities about what types of consumption they would be most willing to reduce and, by extension, have different rationales for their behaviours (see Figure 23). An assumption which more closely approximates reality would be that market players are satisfaction-maximising, and even then, the definition of what this means is relative. This realization introduces complicating considerations into any cost-benefit calculation for any proposed energy efficiency programme calculation.

Taken altogether, it is clear that there are a multitude of determinants that affect the degree to which energy efficiency improvements could deliver positive climactic and economic benefits. Often, this happens in ways that are not entirely predictable through a macro-level, top-down and theoretical analysis.

There are two foreseeable ways to examine the possible effects that non-technical factors would have on energy savings and the resultant emissions savings in a particular setting. The first of these is to find a case of an energy efficiency programme - similar to a proposed one - that has been deployed in a context that is similar to one where an energy efficiency programme is proposed. Then, the aggregate impact that it has had on energy savings and emissions levels can be assessed assuming that accurate data has been collected. While this 'case study' approach at the programme level may give insights into the benefits and challenges that may be encountered in the deployment of such a programme, it is also never the case that every variable can be controlled for, and thus some level of uncertainty will always remain.

The second approach is underpinned by bottom-up, results-oriented logic. Here, pilot activities of the type that a proposed future energy efficiency programme will support are undertaken, and data about their implementation are closely monitored. Ideally, multiple pilots are undertaken in order to increase the sample size within such an experiment. If, within these pilots, there is consistency across cases, such findings can be generalized to a portion or to all building stock with similar properties to those within the pilots. In this way, social, technological, economic, environmental, and political and value dynamics can be controlled for as much as possible. The main shortcoming is that the scaling up of such a programme can encounter administrative, political and financial barriers that smaller scale pilots may not have to face. Such challenges must be considered when contemplating the scale up of such a program. Since such challenges are largely context-dependent, local knowledge is important when doing this. It is the second approach to which we now turn.

2. Real Cases of Energy Efficiency Improvements in Bulgaria

While there are a number of approaches that can be used to measure the effects that building codes and energy efficiency improvements will have on energy savings, Levinson notes that "the best approaches use household-level data and focus on particular programmes." This seems intuitively logical since, at this level, there are fewer variables (i.e. less statistical noise) which need to be controlled for (i.e. occupancy characteristics, variations in climactic zones, differences in the ages of buildings, as new buildings might by their very nature be less airtight etc.). Nevertheless, there are also a number of complicating factors even when using household-level data and which focus on particular programmes. These include increases and decreases in occupancy, changes in income of residents as well as their personal preferences.

Additionally, since no macro-level data was readily available to assess the performance of entire energy efficiency programmes, individual case studies were used to illuminate the potential energy and cost savings that can result from energy efficiency improvements in multi-family residential buildings in Bulgaria.

Energy savings data from the *Sustainable Technologies and Combined Community Approaches Take Off* (STACCATO) project has been obtained from the Sofia Energy Agency. The STACCATO project was initiated in 2007 and was funded under the Concerto initiative of the European Union. The Concerto initiative was a European programme aimed at demonstrating the environmental, economic and social benefits of integrating renewable energy sources together with energy efficiency techniques. In the case of the STACCATO project in Bulgaria, the renovation of five apartment panel blocks, typical of those constructed during central planning was envisaged. These buildings were characterised by very poor thermal characteristics. The following sections detail the energy efficiency improvements for three of these buildings as well as a comparison of the expected versus realised energy savings that resulted from them.

2.1 Case 1: Energy Efficiency Refurbishments in Multi-Family Residential Building (Poduene CENTER, 2 Aleko Konstantinov St.)

This building is a multifamily-residential building with a basement, four floors and an uninhabited attic. It was built in 1950. The building has a total of 16 apartments and the construction of the building consisted of solid-filled concrete with floor and ceiling tiles which have a thickness of 12 cm. No thermal insulation was installed in the basement nor below the ceiling tiles prior to the renovation. The external walls were 30cm think, including solid bricks that were 25cm thick with external and internal plaster (without insulation) that was 5 cm thick. Part of the outer wall of the basement was thermally insulated with 5cm polystyrene. The windows of the building consisted of both wooden and PVC double-paned glass. The building was home to 40 people who lived there year-round and had a total heated floor space of 928 m^2 and with a net heating volume of 2,670 m^3.

Source: Aleko Konstantinov Building before Restoration provided by the Sofia Energy Agency

The renovations to the building included insulation of external walls, insulation of the roof, insulation of the floor, changing of existing wooden and metal doors and windows to insulated PVC doors and windows, and the mounting of water-saving fittings for showers and sinks. These renovations overlap with energy efficiency improvements in the “McKinsey Level 1 Retrofit” noted above, with the exception that the McKinsey retrofit does not include the changing of existing doors and windows or the mounting of water-saving fittings. This goes some way to explaining the finding that the assumptions in McKinsey for such improvements seem to wildly underestimate the costs incurred for these pilot activities by a factor of between 10 and 20. However, as we will see below, while the costs of energy efficiency improvements undertaken within this project are much higher per M^2 than those defined within the McKinsey retrofit, they also appear to save much more energy than the predicted savings from the McKinsey interventions, even when adjusting for aberrant temperature differences between years in Bulgaria.

For reference, the "Level 1 Retrofit" of McKinsey includes the following: improving building air tightness by sealing baseboards and other areas of air leakage, weather stripping doors and windows, insulating attic and wall cavities and adding a basic mechanical ventilation system to ensure air quality. It was assumed that this will result in a 15-25% heating savings potential and up to 10% cooling savings. The retrofit is based on an estimate of 6.26€ per square meter in Western Europe and Japan and scaled down according to GDP. The costs in Eastern Europe are estimated at 3.66€ per square meter.

With the data provided by the Sofia Energy Agency, we determined the energy saved after the renovation as well as the difference, if any, between expected energy savings and realized energy savings using real billing data where data is available. Since the *ex-ante* calculations for energy savings did not include calculations for rebound effects, any aberrations from the expected savings could be an indication of rebound effects resulting from behavioural change. The table below presents baseline, expected and actual heating energy consumption data:

Table 24 – Case 1: Aleko Konstantinov Expected Versus Actual Energy Consumption

Baseline Heating Consumption for Building 2008 (kWh)	120,152
Expected Heating Energy Consumption After Energy Savings Measures (kWh)	No Data[90]
Actual Heating Energy Consumption After Energy Saving Measures 2013 (kWh)	54,718
Actual Heating Energy Consumption Savings after Energy Saving Measures in 2013 (%)	54.46%
Difference Between Expected and Actual Heating Energy Consumption Savings (%)	No Data

Source: Own Calculations Based on Sofia Energy Agency Data

The baseline energy consumption for heating in the building in 2008 was 120,152 kWh per year, and in 2013 after the renovation was completed, 54,718 kWh of energy consumption was recorded. This equates to a nearly 54.46% reduction in energy consumed for heating as a result of the renovations mentioned above.

[90] According to the Director of the Sofia Energy Agency, the expected energy consumption after the renovation was not accurately calculated and is thus unusable.

Source: Aleko Konstantinov Building during Restoration provided by the Sofia Energy Agency

According to data provided by the Sofia Energy Agency as to the total cost of the renovation, we were able to construct the cost per M^2 done simply by dividing the total cost of the renovation by the total heated floor space in the building (928 m^2). Also, the Sofia Energy Agency has determined that a good approximation for determining emissions prevented can be determined by multiplying the energy consumed by .000247 (the amount of CO^2e emitted per kWh of energy consumed). Again, buy dividing this figure by 928 m^2 the amount of emissions prevented by the improvement can be calculated. We then speculate that the amount of emissions that can be prevented by the improvement can be calculated by multiplying this figure for carbon dioxide abated per M^2 by the total square meters of useful dwelling space in the country. The figure for useful dwelling space in the country above was found above to be 265,794,688 m^2 and the total number of emissions which would be abated in the country, if such savings held true for each M^2 in the country, is found by the equation

Equation 19 – Total Emissions Abated

$$E_T = \mathrm{C_A T_D} \tag{13}$$

Where E_T is the total amount of emissions in tCO_2 that would be abated in this scenario, C_A is the number of emissions saved per M^2, and T_D is the total dwelling space in the country in M^2. Similarly, the cost for the abatement for the entire countries dwelling stock, assuming the same cost per M^2 is found by the equation

Equation 20 – Total Cost for Abatement Measures

$$T_C = \mathrm{C_M T_D} \tag{14}$$

Where T_C is the total cost for these abatement measures if applied to the entire country, assuming the exact same average abatement cost per M^2, C_M is the cost per M^2 and where, as above, T_D is the total dwelling space in the country in M^2. It is important to note, however, that this total cost for abatement does not consider the cost savings that will accrue following the refurbishments due to reductions in end-user bills. While it is only these savings that are considered here when determining the payback time following the refurbishments, other savings in transmission and production would also accrue here.

The payback time for these refurbishments is calculated by taking the average heating bill for residents of these refurbished buildings in Bulgaria, calculated at €70.55, and multiplying the by the experienced energy savings of 54.46% calculated above. Thus, the average cost savings for these residents on their energy bill per month was found to be €38.42 (or €461.04 per year) while the average cost for the refurbishment per apartment was €4242.7 and about 1 tCO_2 would be prevented per apartment per year. Given the average size of each apartment of 58 M^2, these refurbishments save residents €.66 per M^2 per month. For this savings to total to the total cost for the abatement measures themselves, 110.42 months would need to pass, or approximately 9.2 years, by which time around 9.2 tCO_2 would have been prevented at zero net cost (excluding the opportunity cost of investing that money and ignoring inflation). To reach the -56.87€ average per tCO_2 abated proposed by McKinsey, between 46 and 47 years will have had to pass with the abatement in place (see Annex 4). It is extremely unlikely that these retrofits will still be function by then.

Scaled up to the entire country level, such improvements would save residential heating consumers €176,066,067 per month.

Table 25 - Case 1: Aleko Konstantinov Cost of Renovation and Payback Time if Generalized

Total Cost	67,906€
Cost Per M^2	73.15€
tCO2 Abated from Renovation in Building per year (assuming no change in behavior or number of residents)	65,434 kWh*.247/1000 = 16.16 tCO_2
Carbon Abated Per M^2 in building per year	.0174 tCO_2
If held true for all dwelling space in Bulgaria	4,624,827 tCO_2 could be abated
Cost for this abatement	19,442,881,427€
Time for Payback	9.2 years

Source: Own Calculations Based on Sofia Energy Agency Data

2.2 Case 2: Energy Efficiency Refurbishments in Multi-Family Residential Building (Asen Zlatarov)

This building is a multi-family residential building consisting of five-floors with a basement, ground floor, and an attic with unheated rooms. It was built in 1932. The building has 13 apartments. The building is made of reinforced concrete and the floor slabs have a thickness of 12 cm. There is no insulation on the ceiling of the basement or on the floor of the attic. The external walls are 37cm thick and made of bricks that are 30cm thick, with external and internal plaster without thermal insulation. The outer door of the building is made of wood and half of its area is made of single glazed glass. The door to the courtyard is made of PVC. The windows and doors of the building include a mixture of those made from wood with double glazed glass, as well as from PVC with double glazed glass. The building is inhabited by about 45 people who live there year round with a total heated floor space of 1,120 m^2 and with a net heated volume of 3,020 m^3.

Source: Asen Zlatarov Building before Restoration provided by the Sofia Energy Agency

As with the previous building, the renovations to the building included insulation of external walls, insulation of the roof, insulation of the floor, changing of existing wooden and metal doors and windows to insulated PVC doors and windows, and the mounting of water-saving fittings for showers and sinks. The heating energy performance of the building before and after the renovations are shown in Table 26.

Table 26 - Case 2 Expected Versus Actual Energy Consumption

Baseline Heating Consumption for Building 2008 (kWh)	142,000
Expected Heating Energy Consumption After Energy Savings Measures (kWh)	66,828
Actual Heating Energy Consumption After Energy Saving Measures in 2013 (kWh)	60,754
Actual Heating Energy Consumption Savings after Energy Saving Measures (%)	57.21%
Difference Between Expected and Actual Heating Energy Consumption Savings (%)	9%

Source: Own Calculations Based on Sofia Energy Agency Data

The baseline energy consumption for heating in the building in 2008 was 142,000 kWh per year, and following the renovation, 60,754 kWh of energy consumption was recorded. This equates to a nearly 57.21% reduction in energy consumed for heating as a result of these renovations.

For calculating the total payback time we again use be average heating bill for residents of these refurbished buildings in Bulgaria, calculated at €70.55. We multiple this amount by the savings following the renovation of 57.21%, to get a value of €40.36. Since the average size of an apartment in this building is 86 m^2 these refurbishments save residents €.47 per M^2 per month. Scaled up to the entire country level, such improvements would save residential heating consumers €124,738,065 per month. For this savings to total to the total cost for the abatement measures themselves, 150.61 months would need to pass, or approximately 12.5 years.

Table 27 - Case 2: Asen Zlatarov Cost of Renovation and Payback Time if Generalized

Total Cost	79,166€
Cost Per M^2	70.68€
tCO2 Abated from Renovation in Building (assuming no change in behavior or number of residents)	81,246 kWh*.247/1000 = 20.07 tCO_2
Carbon Abated Per M^2 in building	.0179 tCO^2
If held true for all dwelling space in Bulgaria	4,757,724 tCO^2 could be abated
Cost for this abatement	18,786,368,547€
Time for Payback	12.5 years

Source: Own Calculations Based on Sofia Energy Agency Data

2.3 Case 3: Energy Efficiency Refurbishments in Multi-Family Residential Building (Chataldja)

This multifamily residential building consists of three floors and a basement, as well as an attic with two studios and an uninhabited section. It was built in 1957. There are a total of 19 apartments in the building. The construction of the building is reinforced concrete. The floor and ceiling concrete slabs have a thickness of 12 cm. Insulation is missing on the floor over the basement as well as on the floor of the attic. Over the attic and part of the attic studio apartments, the roof is wooden and covered with wood siding, oilcloth and ceramic tiles. The external walls have a thickness 30cm. This is made with bricks that are 25cm thick and have external and internal plaster without thermal insulation. The outer door of the building was made with metal and made with single glazed glass. The windows of the residential premises are both wooden and PVC with double-pane windows.
The building is inhabited by 61 people who live there year round with a total heated floor space of 1,240 m^2 and with a net heated volume of 3,450 m^3.

Source: Chataldja Building before Restoration provided by the Sofia Energy Agency

As with the previous buildings, the renovations to the building included insulation of external walls, insulation of the roof, insulation of the floor, changing of existing wooden and metal doors and windows to insulated PVC doors and windows, and the mounting of water-saving fittings for showers and sinks. The renovations were completed in 2011.

Table 28 - Case 3 Expected Versus Actual Energy Consumption

Baseline Heating Consumption for Building 2008 (kWh)	125,944
Expected Heating Energy Consumption After Energy Savings Measures (kWh)	80,053
Actual Heating Energy Consumption After Energy Saving Measures in 2013 (kWh)	91,988
Actual Heating Energy Consumption Savings after Energy Saving Measures (%)	26.96%
Difference Between Expected and Actual Heating Energy Consumption Savings (%)	-14.9%

Source: Own Calculations Based on Sofia Energy Agency Data

The baseline energy consumption for heating in the building in 2008 was 125,944 kWh per year, and following the renovation, 91,988 kWh of energy consumption was recorded. This equates to a nearly 26.96% reduction in energy consumed for heating as a result of these renovations.

Source: Chataldja Building after Restoration provided by the Sofia Energy Agency

Since no total cost data was available for this building, the generalized cost for this abatement, as well as the total payback time cannot be calculated.

Table 29 - Case 3: Chataldja Cost of Renovation and Payback Time if Generalized

Total Cost	No Data

Cost Per M^2	No Data
tCO2 Abated from Renovation in Building (assuming no change in behavior or number of residents)	33,956 kWh*.247/1000 = 8.38 tCO_2
Carbon Abated Per M^2 in building	.0068 tCO^2
If held true for all dwelling space in Bulgaria	1,807,403 tCO^2 could be abated
Cost for this abatement	No Data
Time for Payback	No Data

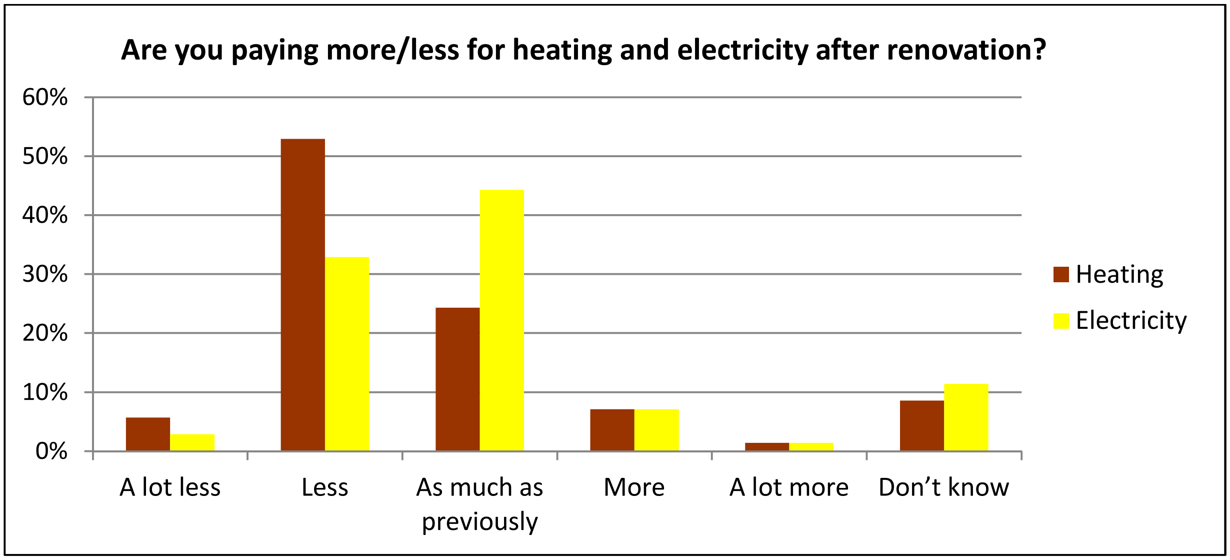
Source: Own Calculations Based on Sofia Energy Agency Data

3. Comparison of the Abatement Cost Models with Real Case-Based Data

An analysis of these energy efficiency pilot activities in Bulgaria uncovers some important dynamics in the implementation of energy efficiency measures in multi-family residential buildings in Bulgaria. The estimates of expected versus achieved energy savings appear, in the main, to not be far off and go some ways to assuaging concerns about rebound effects - although a larger sample size of renovated buildings would be helpful in increasing the robustness of these findings .

In the second case of Asen Zlatarov, the actual heating energy consumption was 9% less in 2013 than the predicted energy consumption after renovation. In the third case of the Chataldja block, the actual heating consumption exceeded the expected heating consumption by 14.9%. At least in these two cases, it appears that energy savings approximated the technical engineering estimates. This is shaded somewhat differently however by the final report of the STACCATO project which displays the results of a survey of residents regarding their heating costs after the renovation. Of the 42 respondents that replied to the question about whether they were paying more or less for heating and electricity after the renovation, the perception of results were not as clear as the real billing data would have us believe, as Table 29 illuminates.

Figure 24 – Responses to the Question "Are you paying more/less for heating and electricity after renovation?" - Bulgaria



Source: STACCATO Project

According to this, nearly 60% of residents in the renovated dwellings reported that they were paying either "less" or "a lot less" for heating after the renovation, and 35.8% said that they were paying either "less" or "a lot less" for electricity. Over 20% of respondents said that they were paying "as much as previously" or "more" for heating, and this figure was 51.4% for electricity. Such a discrepancy between self-reported costs and the real energy consumption data for heating may result from a plethora of factors, including a self-selection of those who did not experience a reduction in costs disproportionately participating in the questionnaire or as a result of respondents answering incorrectly and without full knowledge of the impacts that the renovations have had on their bills.

In our attempts to reconcile the costs of emissions abatement using the abatement cost models with the data obtained from the three refurbished multi-family buildings, we need to acknowledge some key differences between what these two pieces of information can tell us – as well as what new knowledge can be generated from looking at them in parallel. While the refurbishments which were undertaken in Sofia were much more expensive than those classified as "Level 1 Refurbishments" by McKinsey, they also translated into much deeper energy consumption and emissions cuts than the 15-25% heating savings potential and up to 10% cooling savings anticipated there. In actuality, with these deeper and more expensive cuts, we see energy and emissions reductions exceeding 50% with paybacks calculated at around 10 years (assuming that energy costs remain flat). But the total costs of such improvements, if applied to the whole country, are likely too high for Bulgarian society to bear. Completing interests for these public funds would almost certainly take priority long before these allocation levels were reached.

The question that this begs then is what the optimal emissions cutback level is for expenditures on energy efficiency improvements for a particular society. The cost models show that over the five year period from 2015-2020, 2.61 $MtCO_2$ can be expected to be abated out of a total of 260.456 $MtCO_2e$ – almost exactly 1% of emissions for these years and can be done at costs ranging from just over -€148 million (in the McKinsey Model) to $80 million in the EMF-22 Model. It would be hard to argue that these relatively inexpensive opportunities should not be captured but also that the more expensive cutbacks, as total emissions reductions approach 100% should be as well. Indeed, society will surely benefit from allocating these resources elsewhere (i.e. in healthcare, job creation and infrastructural improvements).

However, similarly to the Laffer Curve for taxation – a concept highlighting that there must be at least one tax rate when tax revenue would be a non-zero maximum amount of revenue for the body collecting it – there must also theoretically be an ideal emissions cutback level between 0% and 100% *where the economic, social and environmental benefits of energy efficiency improvements result in non-zero maximum value to society*. There are basic energy efficiency improvements, such as improving air tightness and the weather-stripping of doors and windows, which have payback periods so short that they effectively pay for themselves in a matter of months and start bearing returns thereafter. Other energy efficiency improvements may have such long pay back periods that the improvement would deteriorate before its full cost is recuperated. Clearly, the above data shows that basic energy efficiency improvements can save substantial amounts of energy; the important question though, is how much should be saved?

Calculating the economic costs of each energy efficiency improvement and the amount of emissions that it can abate, although difficult, it the most straightforward part of this task. While attempts to quantify the environmental costs to society of each ton of carbon emitted (i.e. health care costs, unemployment costs, clean-up costs) can be undertaken, these too run into significant headwinds in that many of these economic calculations assume that natural capital is substitutable with financial capital – an assumption which falls apart under scrutiny since natural capital is, in many cases non-substitutable. From a social perspective, we have even less of an idea of how to assess the costs from these emissions to human happiness that is derived from living in a clean, healthy natural environment.

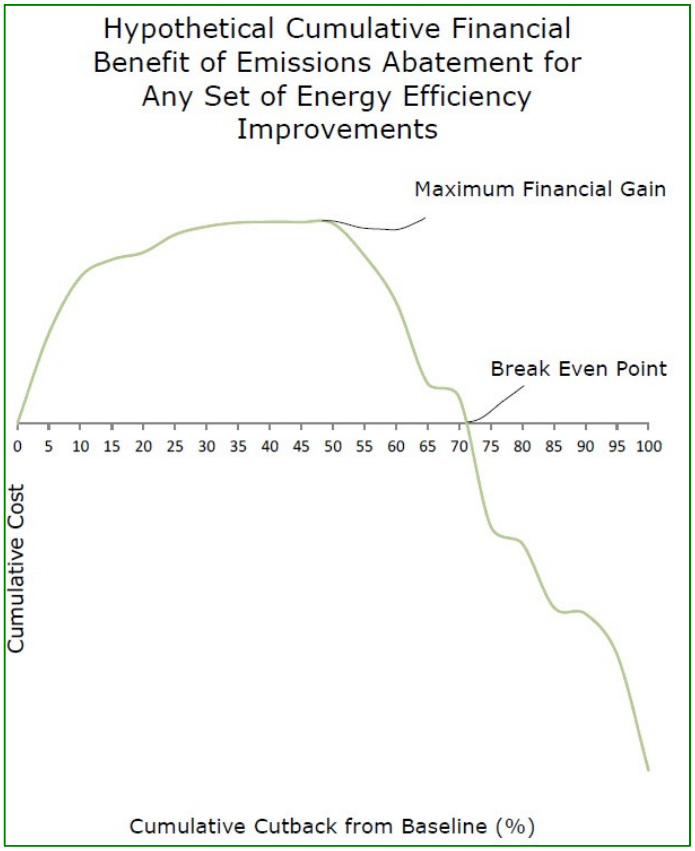
Considering these factors, we can see that the bare minimum threshold for energy efficiency improvements is the level at which they are cost neutral to society. When we see that even this threshold has not been met, then intervention is necessary to capture these benefits.

So, let us put this concept in economic terms. In doing so, we can expect that the shape of such an Energy Efficiency Laffer Curve would not start at zero financial gains and end at zero financial gains as the classic Laffer Curve for taxation, but would rather start at no financial gains at the y-axis (0% cutbacks) where there would be no energy efficiency improvements, it rise very quickly as low-cost, high-impact improvements were made, these increases would reduce in magnitude until they started to decrease where energy efficiency improvements started to incur positive costs. This point is labelled as Maximum Financial Gain in Table 30 below.

The total financial gains would then decrease to some percentage cutback that crossed the x-axis (where all aggregated energy efficiency improvements resulted in no net-gain or net-loss). This is labelled as the Break Even Point in Figure 23.

Then the curve enters net-loss territory (this happens in the hypothetical curve below at around 71%) as cutbacks approach 100%. It is clear from the theoretical models that these low-hanging fruits have not been completely captured and such a curve may show us that it may be misplaced to focus on deep-cutbacks of the type undertaken in the STACCATO project from a cost-benefit perspective, since some of the individual improvements used at this depth of renovation do not maximize the financial gains that could be seen from undertaking more promising interventions.

Figure 25 - Hypothetical Cumulative Financial Benefit of Emissions Abatement for Any Set of Energy Efficiency Improvements



Source: Own Figure

It is important to note in this figure, that the last abatement opportunity with non-negative costs exists at around 45% emissions cutback from baseline. After this point, all abatement opportunities within this set of improvements have positive costs. While the abatement opportunities between 45% and 71% cutback from baseline have positive costs, the *aggregate cost* is still negative. It is important to note that this this table is only conceptual and based on fabricated figures for 20 hypothetical abatement opportunities, we did find above in the cost models that abatement costs turned infinite at a 77% cutback from baseline, so the break-even cost point is probably significantly lower for most countries than what is indicated herein.

It is important to reiterate that this model is overly simplistic and does not incorporate the long term economic and non-economic benefits resulting from an improved natural environment and reduced social ills emanating from increased pollution. Resultantly, this “Break Even Point” is the bare minimum of what should rationally be achieved by society in fighting climate change and calculated simply because this is what can be quantified. The actual theoretical Break Even that incorporates these non-economic considerations is theoretically somewhere between this level and 100% emissions reductions. Technological innovation which decreases the costs of carbon abatement or those which can capture harmful emissions from the air could make this Break Even Point over 100%. This would mean that the Break Even Point of costs versus benefits would be a realm not only where society was greenhouse gas neutral, but rather where it was greenhouse gas negative.

4. Current Financial Outlays on Energy Efficiency Measures for Residential Buildings in Bulgaria

While the field of economics is generally not amenable to conducting controlled experiments, we can infer both from theoretical and real case based data about the effects of particular phenomena on economic outcomes. We aim to do this by combining theoretical cost models for carbon abatement with real-case based data in order to determine the differences between commonly conducted energy efficiency refurbishments in residential buildings and cost-optimality for the expenditure of public funds from all possible energy efficiency improvements.

In doing so, we will approximate the total financial outlays available for energy efficiency improvements in residential buildings in Bulgaria. Then we will determine how much energy and emissions these funds could save if they were used in a similar way to the cases from the STACCATO project above. We will then compare this cost and emissions savings to the energy and emissions savings that would be possible if these funds were spent on the most optimal energy efficiency interventions possible according to the CRED, RICE and EMF-22 cost models above.

Approximate Financial Outlays for Energy Efficiency Improvements in Residential Buildings

Table 33 below shows the financial outlays that are currently committed to energy efficiency in Bulgaria. While it is not possible to claim with certainty that all of these funds are available for energy efficiency in residential buildings, these are the available funds that could either be used on energy efficiency in residential buildings in Bulgaria or on a battery of cost-optimal energy efficiency improvements.

Table 30 – Programs and Financial Mechanisms for Energy Efficiency in Bulgaria

PROGRAMS AND FINANCIAL MECHANISMS FOR ENERGY EFFICIENCY IN BULGARIA	
Program or financial instrument	**Total budget:**
Фонд „Енергийна ефективност и възобновяеми източници" / ENERGY EFFICIENCY AND RENEWABLE SOURCES FUND - http://www.bgeef.com/display.aspx	67,800,000 лв.
Оперативна програма „Иновации и конкурентоспособнос" 2014 - 2020 / Operative program "Innovation and competitiveness"	516,502,700 лв. *Divided by the 7 years of the program: 73,786,100 BGN*
НАЦИОНАЛНА ПРОГРАМА ЗА ЕНЕРГИЙНА ЕФЕКТИВНОСТ НА МНОГОФАМИЛНИ ЖИЛИЩНИ СГРАДИ 2015 - 2016 г. / National Programme for energy efficiency of multifamily buildings	1,000,000,000 лв. *Divided by the 2 years of the program: 500,000,000 BGN*
ОП „Региони в растеж 2014-2020" / Operative program "Regions in development" 2014 - 2020	435,954,507 лв. *Divided by the 7 years of the program: 62,279,215 BGN*
Програма BG04 "Енергийна ефективност и възобновяема енергия" - Грантова схема BG 04-04-05 - BG04 PROGRAMME ENERGY EFFICIENCY AND RENEWABLE ENERGY- www.energygrantsbg.org	31,293,280 лв.
	2,051,550,487 лв.

Source: Own Table

As can be seen in this table, €1,049,038,386 (2,051,550,487 BGN) is currently allocated from all public funding programmes from 2015-2020. Assuming that these financial instruments are distributed linearly over their duration for the multi-year instruments, and financial outlays remain the same each year from 2016-2020 for the annually allocated funding sources, we find that an average of €375,912,582 (735,158,595 BGN) would be available each year from 2015-2020.

Energy and Emissions Savings Based on STACCATO

In the STACCATO pilot projects, we saw that the average energy savings before and after refurbishment was 46.21%. For these purposes herein we will underestimate this value slightly to be safe and calculate it to be 45% energy savings after refurbishment. The total cost per M^2 of these buildings for this renovation, for which there was data, was €71.9. Using these figures, 14,590,241 M^2 could be renovated to this depth assuming no economies of scale and similar costs for all renovations. This would mean that of the total of 265,794,688 m^2 of current useable refurbished dwelling floor space in Bulgaria, that 5.49% of the total residential building stock in the country could be renovated with these renovations and 45% of their energy use and emissions could be eliminated – or 2.47% of all energy and emissions from residential buildings in the country. As the residential sector consumes 25.7% (2012 est.) of all energy in the country, such a refurbishment would prevent the emissions of approximately .6% of all emissions in Bulgaria assuming that all sectors energy consumption had similar energy intensities. Given the calculated level of emissions above at 48,406 *KtCO2* using the Cline equation, this would equate to a savings of 290 *KtCO2* annually following the completion of the refurbishment (or .000290 $GtC0_2$ and .000079 in GtC).

Comparing this financial outlay of 735,158,595 BGN to the three cost models above provides noticeably different results. In these cost models, the price to the economy is calculated as the cost as a percentage of GDP. According to the International Monetary Fund's estimates, the average Bulgarian GDP in these years in current prices will be 88.7 billion BGN. Thus, the average available amount of financing in these years, calculated above at 735,158,595 BGN, equates to an average cost of .83% of GDP between 2015 and 2020. Considering the average GDP in current prices for Bulgaria between 2015 and 2019 is $66.42 billion according to the International Monetary Fund, .83% of GDP would be an average of $551,318,000. This figure is needed to use the CRED-Two Parameter equation. Doing this we find that

- *According to the CRED-Two Parameter Model 28,500 KtCO2 a 58.8% cutback (.0285 $GtC0_2$ or .00777 in GtC) could be abated with this financing annually;*

- *According to the Nordhaus RICE Model 29,360 KtCO2 a 60% cutback (.02936 GtC0_2 or .008 in GtC) could be abated with this financing annually;*
- *According to the EMF-22 Model 19,671 KtCO2 a 40% cutback (.01967 GtC0_2 .00536 in GtC) could be abated with this financing annually.*

That these numbers are around 100 times higher than the carbon abatement estimates developed by generalizing the real case-based data gives pause. This extremely large discrepancy could result from a number of causes such as: (1) the cost models are not applicable in relatively small economies like Bulgaria, (2) the savings and costs experienced through the real-case based data in the STACCATO project are not representative of the savings and costs that might be experienced were similar measures applied to the building stock as a whole, (3) that energy efficiency improvements of the type that were implemented within the real-cases are not as efficient as some other types of energy efficiency improvements might be or (4) the financial outlays which are currently allocated will not be used in their entirety for actual energy and carbon efficiency improvements and much of these funds will be used on program administration and other non-technical costs.

Points (1) cannot be further investigated without more deeply probing the nature of the model and point (2) would need to be addressed through the availability and examination off a more robust data set. However, we can gain some insights into point (4). A brief survey shows that the administrative costs of public programs can range from 1% to 10% of total programme spending. The costs of administering particular energy efficiency programmes show administrative costs of between 8.5% and 15% of the total programme cost.[91]

Depending on the depth of incentives that are made available through these programmes for potential recipients (i.e. do they cover 100% of improvement costs or less), the degree to which the remainder of the financing can stimulate improvements can vary wildly. Herein we assume that the programmes listed above cover 100% of the costs. This seems a valid assumption given the case made above that the possibility for the majority of Bulgaria's to assume such costs are small. Therefore, if we assume administrative costs on the high end at 15%, we find that of the total of 735,158,595 BGN available annually, 624,884,805 BGN would be available annually or .7% of GDP. Again, considering the average GDP in current prices for Bulgaria between 2015 and 2019 is $66.42 billion according to the International Monetary Fund, .7% of GDP would be an average of

[91] National Action Plan for Energy Efficiency (2008). *Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers*. Energy and Environmental Economics, Inc. and Regulatory Assistance Project. www.epa.gov/eeactionplan

$464,940,000,000. This figure is needed to use the CRED-Two Parameter equation. Doing this we find that

- *According to the CRED-Two Parameter Model 26,400 KtCO2, or a 54.4% cutback (.0264 GtC0$_2$ or .0072 in GtC) could be abated with this financing annually;*
- *According to the Nordhaus RICE Model 27,890 KtCO2, or a 57% cutback (.02789 GtC0$_2$ or .0076 in GtC) could be abated with this financing annually;*
- *According to the EMF-22 Model 17,610 KtCO2, or a 36% cutback (.01761 GtC0$_2$ .0048 in GtC) could be abated with this financing annually.*

Even with 15% administrative costs included in this estimation, significantly high cutbacks are estimated using the cost models. This would indicate that there are a number of more cost optimal interventions to reduce carbon emissions than those used in the STACCATO project. According to a McKinsey report these interventions include switching incandescent lights to LEDs for residential and commercial applications, more efficient residential and consumer electronics, and a plethora of other interventions [92]

Additionally, according to the EVAL-INNO project about 1-2% of a programs budget (smaller for bigger projects and bigger for smaller projects) should be kept aside for project evaluation. This is something that appears to both be lacking significantly in European Funded projects as well as those at the national level.

The *Third National Action Plan on Climate Change* estimated the aggregate GHG emissions in Bulgaria in 2009 to be 59.496 MtCO$_2$e. With all measures already approved by that year, it estimated emissions in 2020 to be 61.864 MtCO2e and in 2030 it put this figure at 60.943 MtCO2e. Including the adoption of all future measures that the action plan outlined after 2009, it foresaw the potential for reductions to 54.578 Mt CO$_2$e in 2020 (a reduction of 7.286 Mt CO2 eq.) and 52.642 Mt CO2 eq. in 2030 (a reduction of 8.301) Mt CO$_2$e with additional measures. According to abatement cost models above, .87 Mt CO2 eq. could be abated at negative or negligible net cost.

The Cline approach to calculating emissions resulted in an estimate of 48,406 Mt CO$_2$eq. in 2020, a level somewhat below that estimated in the Bulgarian policy documents. This illustrates the difficulties in constructing a baseline scenario due to built-in assumptions, as well as highlights its importance in determining how far

[92] McKinsey & Company. (2009). Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve. <http://globalghgcostcurve.bymckinsey.com>, Retrieved on 19.8.2012

emissions cutbacks are possible and what could possibly be expected with available financial outlays. For example, the emissions level in 2020 in Bulgaria, calculated herein, is forecasted to be below what is expected in the *Third National Action Plan on Climate Change* even with additional measures. As such, according to this, if no additional measures were taken and the forecasting assumptions used in constructing the estimate under Cline held true, the targets in this action plan will be met easily without taking any additional action.

Now, since there may be .7% of GDP available annually (both from national and European funding programmes) for energy efficiency improvements in the country, according to the three cost models, emissions reductions from 36% to 57% are possible. Even after excluding the Operational Programmes from this estimate, since we are not sure how much of these funds will go to energy efficiency and renewable energy improvements via-a-vis other competing uses, .67% of GDP would be available, having only a negligible effect on these estimates.

As with any emissions forecast, and as with the abatement models, the validity of the assumptions on which they rest can and should be questioned. Even so, this result may be grounds to reconsider what emissions baseline is used to calculate cutbacks, as well as what level of cutbacks from a BAU scenario are possible. If anything, it shows that while improving energy efficiency in residential buildings may indeed be a societally beneficial public policy, the depth and the resultant cost at which these improvements are made and the resultant benefits from them, should be weighed against alternative, potentially more cost optimal energy efficiency options.

5. Implications for Bulgarian Energy Efficiency Policy

5.1. Supporting and Funding Energy Efficiency Improvements

While the findings of the top-down cost calculation models are theoretically interesting, from a public policy perspective, they leave much unexplored. Before public money is deployed in the achievement of desired socio-economic ends, investigations of public perceptions amongst the citizenry of such policies are helpful in assuaging (or confirming) the practical concerns of policy-makers. Georgetown University economist Arik Levinson highlights the trap that policy-makers and their constituents can fall into when considering the promise of energy efficiency, when he writes that "efficiency standards appeal politically because they purport to conserve scarce resources while savings consumers money – a costless public policy."[93]

Levinson highlights an inherent contradiction in improving energy efficiency that economists find troubling when using it as a policy tool – that improving energy efficiency makes consumption (and the resulting pollution) cheaper - when economic logic would dictate that, to stimulate a reduction in consumption, energy should be made more expensive. He and others note that the promotion of energy efficiency is likely to work better as a tool to reduce resource consumption, and stimulate innovation, when it is paired with a green tax that keeps the cost per unit of energy services supplied stable at the cost level prior to efficiency improvements. While the energy efficiency interventions noted above focus on promoting energy efficiency through grants and direct subsidies, regulatory mechanisms that motivate behavioural change also be helpful in the quest towards achieving increased efficiency. Since there are untapped energy efficiency improvements with little or small costs, increasing taxes on consumption (or similarly, removing subsidies on consumption) could incentivize individuals to increase the efficiency of their own personal and professional behaviours.

Using taxation policy, such as a green tax, to drive changes in user behaviour in Bulgaria can be examined in data obtained from the *Parliaments and Civil Society in Technology Assessment (PACITA)* project. During this event, citizens were asked whether they thought that the basis for calculating tax obligations should be based on consumption rather than income. The results for each country are listed in Table 23 with the results for Bulgaria highlighted.

Table 31 – Responses to question "Should taxes be shifted from income towards taxes on consumption and resource use?" by country

Should taxes be shifted from income towards taxes on consumption and resource use?				
location			Frequency	Percent
Austria	Valid	No	23	22.1
		Yes	72	69.2
		Prefer not to answer	8	7.7
		No answer	1	1.0
		Total	104	100.0
Belgium	Valid	No	16	15.2
		Yes	56	53.3

[93] Levinson, Arik. *California energy efficiency: Lessons for the rest of the world, or not?* Journal of Economic Behavior & Organization, April 26th, 2014.

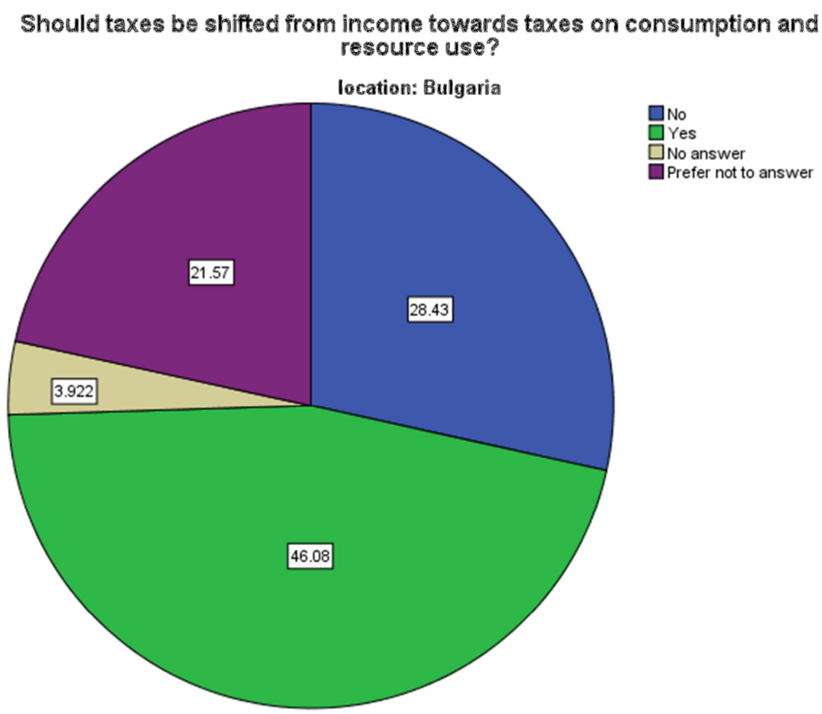
		Prefer not to answer	28	26.7
		No answer	5	4.8
		Total	105	100.0
Bulgaria	Valid	No	29	28.4
		Yes	47	46.1
		Prefer not to answer	22	21.6
		No answer	4	3.9
		Total	102	100.0
Czech Republic	Valid	No	15	14.2
		Yes	67	63.2
		Prefer not to answer	23	21.7
		No answer	1	.9
		Total	106	100.0
Denmark	Valid	No	42	38.2
		Yes	58	52.7
		Prefer not to answer	9	8.2
		No answer	1	.9
		Total	110	100.0
Hungary	Valid	No	42	37.8
		Yes	55	49.5
		Prefer not to answer	12	10.8
		No answer	2	1.8
		Total	111	100.0
Ireland	Valid	No	7	14.0
		Yes	39	78.0
		Prefer not to answer	4	8.0
		Total	50	100.0
Lithuania	Valid	No	24	24.2
		Yes	62	62.6
		Prefer not to answer	12	12.1
		No answer	1	1.0
		Total	99	100.0
Netherlands	Valid	No	27	29.7
		Yes	58	63.7
		Prefer not to answer	4	4.4
		No answer	2	2.2
		Total	91	100.0
Portugal	Valid	No	14	13.2

		Yes	65	61.3
		Prefer not to answer	25	23.6
		No answer	2	1.9
		Total	106	100.0
Spain	Valid	No	7	16.7
		Yes	23	54.8
		Prefer not to answer	11	26.2
		No answer	1	2.4
		Total	42	100.0

Source: Own Table Constructed Using SPSS

Interestingly, the lowest percentage of respondents from any country who thought that the basis for taxes should be shifted from income to consumption (the specific type of consumption was not defined) was in Bulgaria (46.1%). These figures, based on responses from 102 citizen participants, are visualized below in Figure 26.

Figure 26 – Responses to question "Should taxes be shifted from income towards taxes on consumption and resource use?" in Bulgaria



Source: Own Figure

In order to more accurately compare the results from Bulgaria to an aggregate value of all 11 European Union countries and 1026 respondents, the results from Table 23 were totalled and weighted by the population size of each country. This allows for a more accurate representation of the opinions of European citizens as a whole. Although attempts were made to achieve representative samples from each country, the researchers made no claim that representativeness was achieved. After performing this weighting, it was found that percentage of all respondents who answered affirmatively to the above question was somewhat higher, at 58.09%, than in Bulgaria alone (see Table 24 for unweighted data and Table 25 for weighted data).

Table 32 - Responses to question "Should taxes be shifted from income towards taxes on consumption and resource use?" all countries, Unweighted

Should taxes be shifted from income towards taxes on consumption and resource use?			
		Frequency	Percent
Valid	No	246	24.0
	Yes	602	58.7
	No answer	20	1.9
	Prefer not to answer	158	15.4
	Total	1026	100.0

Source: Own Table Constructed Using SPSS

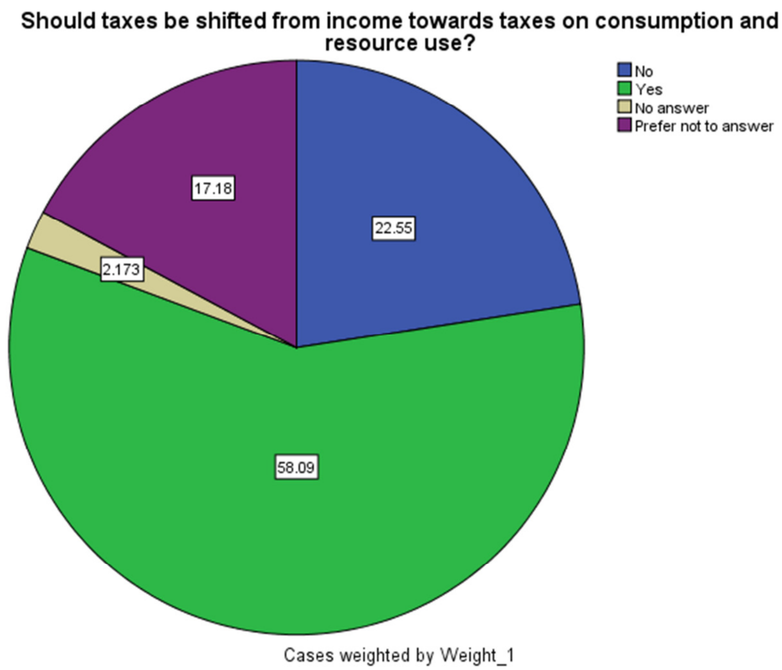
Table 33 - Responses to question "Should taxes be shifted from income towards taxes on consumption and resource use?" all countries, Weighted

Should taxes be shifted from income towards taxes on consumption and resource use?			
		Frequency	Percent
Valid	No	823	22.6
	Yes	2120	58.1
	No answer	79	2.2
	Prefer not to answer	627	17.2
	Total	3649	100.0

Source: Own Table Constructed Using SPSS

It should be noted in Table 35 that the total sample size of 3,649 is an artefact of the weighting protocol used in SPSS. Each of the 1,026 real observations is multiplied by the weight given to that specific observation (and calculated based on the total population for that country) and then totalled. While this does not create any issues for the purposes needed herein of calculating weighted percentages, it creates inaccuracies when performing other statistical manipulations on the data in that it increases the perceived robustness of the data. The weighted data from Table 25 is presented below in Figure 27.

Figure 27 - Responses to question "Should taxes be shifted from income towards taxes on consumption and resource use?" all countries, Weighted



Source: Own Figure

The population data for each country in Table 26, on which the weighting are based, come from Eurostat data from 2014.[94]

Table 26 – Populations by Country and Weightings Given to Data

Country	*Population*	*Weight 1*
Austria	8,506,889	2.890
Belgium	11,203,992	3.806
Bulgaria	7,245,677	2.462
Czech Republic	10,512,419	3.571
Denmark	5,627,235	1.912

[94] Eurostat – Population change – Demographic balance and crude rates at national level [demo-gind]. Last accessed on April 18th, 2015.

Hungary	9,877,365	3.356
Ireland	4,605,501	1.565
Lithuania	2,943,472	1.000
Netherlands	16,829,289	5.717
Portugal	10,427,301	3.543
Spain	46,512,199	15.802
Total	134,291,339	

Source: Own Table Constructed Using Eurostat Data

While no claim of statistical representativeness of the data was made, the sample size was 1,026 and was fairly gender balanced at 55% percent male. The age distribution of the participants can be seen in Table 27 and illustrates a fairly equal distribution across all categories, with a slightly higher representation amongst the youngest (18-29) age group. To varying degrees, the gender and age distributions do not represent the dynamics of the general population in each country. As such, both for the gender and age categories, as with the modifications made according to the total population of each country above to calculate and better assess Europe-wide sentiment, weightings could be applied to each response according to the real gender distribution and real age distribution in each country in order to adjust for unrepresentativeness. This is only necessary if we find that gender or age correlate to the response to the question asked. However, it is not within the purview of the current investigation to make these adjustments or uncover these correlates. While extreme caution must be exercised in extrapolating and generalizing from such data, the data is still useful for the purposes herein.

Table 27 – Age Distribution in the PACITA World Wide View Event

Age Distribution			
		Frequency	Percent
Valid	18-29	242	23.6
	30-39	177	17.3
	40-49	181	17.6
	50-59	190	18.5
	60-69	169	16.5
	70+	66	6.4
	Not answered	1	.1
	Total	1026	100.0

Source: Own Figure Based on PACITA data using SPSS

We cautiously infer from the data that the notion of a tax on consumption, or a so called "green tax", is not something that would be easily accepted in Europe even when it was coupled with a decrease in income taxes. This also appears to hold true, perhaps even to a greater extent, in Bulgaria where a slight minority of responded agreed that taxes should be shifted from being based on income to being based on consumption. Thus, if a focus on energy efficiency in Bulgaria, and in Europe, becomes a cornerstone of environmental, economic and/or social policy, it should be noted that the possibilities for mitigating unintended rebound effects, through taxation on consumption, may be politically troublesome. By extension, attempts to incentivise energy efficiency through the use of price manipulation (e.g. by increasing energy taxes) is not something that the majority of Bulgarian society seems prepared to bear.

It must be borne in mind that the current level of taxation on energy and on income varies wildly across the countries listed above. These different taxation baselines would almost certainly have varying effects on the respondent's responses to this survey, assuming that there were no informational asymmetries regarding their knowledge of such tax levels. While this does not necessarily mean that cross-country comparisons are not meaningful, a deeper investigation into the underlying causes of these responses could include a cross-country qualitative comparison of existing income taxation and taxation on consumables.

5.2. Discussion

The maintenance of biodiversity, and avoidance of catastrophic shocks to human habitation, requires that an increase in global mean temperatures do not rise beyond 2°C; this is the threshold below which an overwhelming consensus of climate scientists believes the most serious effects of global warming can be avoided. The most prominent barrier to national and global action on this issue is not technological or financial, but political. The politics of climate change, and those politicians which work within them, are bound by the system within which they find themselves. In a competitive global economic environment, and even within countries when regions or states are vying for investment, the fear of losing jobs for their constituents is very real. However, the perceived causal relationship between instituting policies and programmes that reduce emissions, and reductions in competitiveness, are often unquestioned. A number of studies allude to either negative or extremely low costs for emissions abatement from some abatement interventions.

Bulgaria has the most energy intense economy in the European Union, partially as a calculation dynamic resulting from its low GDP per capita, but also as a result of its low level of energy efficiency in buildings, and also due to infrastructural inefficiencies in the creation and transmission of energy, which make improvements in energy efficiency an important area of focus. As such, this study aimed to examine the level of emissions that could be abated at negative cost through residential building retrofits as outlined by a McKinsey study, as well as investigated the costs in abating various levels of carbon in the country according to three different cost models. In doing so, a baseline estimate of emissions was needed to 2020 so that potential emissions cutbacks, and their costs, could be measured against it. The McKinsey approach was scaled down and applied to the Bulgarian case and by its very nature showed negative abatement costs. However, when the costs of implementing the McKinsey interventions were compared with real-case based data for retrofits, it was found that, while the real cases saved about double the emissions that the McKinsey intervention predicted, that they were on average nearly ten times as expensive.

Further, the total financial outlays for energy efficiency in 2015 was determined and assumed to remain consistent until 2020. If all of these funds were used for the same interventions and at the same cost as the real-case based data, it was found that 290 KtCO2 could be prevented annually. This level of financing was then used in the cost curves to determine what level of emissions cutbacks from baseline could be expected. These baseline cutbacks were calculated at from between 36% to 57% if used in the most cost optimal way possible. There is a caveat here though that must be noted. The values for the constants in these cost curves were calculated as if action started in 2010. When this study was initiated in 2011, these calculated values were still essentially valid. Now, four years later, in 2015, the costs of achieving this degree of cutbacks from baseline by 2020 would logically be more expensive. In actuality, these costs as a percentage of GDP probably correspond more accurately to the achievement of these cutbacks from baseline by 2025 rather than by 2020.

Nevertheless, a cutback of .6% from baseline, were the available financing only used for the generalization of the energy efficiency improvements used in STACCATO, are significantly smaller than the potential cutbacks using the cost models. This implies that even this somewhat basic level of refurbishment may not be cost optimal in improving Bulgaria’s energy efficiency profile. Many publicly funded energy efficiency programs appear on their face to be a good use of public money. They can hypothetically save struggling energy consumers money at the same time as they contribute to environmental protection and the fight against climate change.

The findings here allude to the fact that the opportunity costs of other forgone energy efficiency improvements might make the assumption fallacious that any degree of energy efficiency improvement in buildings is good, or at the very least, bring it into question. A thorough examination of all possible (or at least multiple competing) interventions would be one approach in ensuring that such financing is achieving its goals more optimally. For example, less intensive retrofits on a higher number of buildings, such as providing weather-stripping on doors and windows and hiring knowledgeable technicians to install it, may be better placed. More "high-tech" and politically visible interventions, such as the financing of zero-energy buildings might be more appealing to public authorities, but have much less promising cost-benefit ratios. A generally safe takeaway from the findings is that while deep energy efficiency improvements in buildings might deliver some benefits, their cost-optimality should be questioned.

Further consideration of this issue can reveal more complicated motivations for choosing a particular programme or policy over another, and may show invocations the social dimensions to energy policy. The buildings within the STACCATO project, and within a number of other energy interventions in Bulgaria, prioritize the renovation of buildings with socio-economically disadvantaged residents. As discussed above, energy poverty levels in Bulgaria are relatively high compared to the EU average, and it may be seen as societally beneficial to disproportionately prioritize such groups when designing energy efficiency policies. In such instances however, trade-offs are made between the economic, environmental and the social goods that are delivered by a particular public policy.

However, such conclusions should be seen in light of the limitations of this study. In calculating the projected emissions levels in Bulgaria between 2015 and 2020, a number of data sets were used which themselves have built-in assumptions that may or may not prove to be true. The growth rate of the Bulgarian population, the growth rate of GDP per capita, the output per unit of energy, and the carbon efficiency of energy all have varying degrees of uncertainty. The rate at which the Bulgarian population will change over time is the least uncertain of all of these projections as evidenced by the relatively small differences in the Upper (UCL) and Lower Control Limits (LCL) as compared to the other projections. Conversely, the most uncertain of these projections is that for the carbon efficiency of energy, where the UCLs and LCLs diverge drastically starting in 2015.

Secondly, for the three cost models that were deployed, major assumptions had to be made as to which cost parameters to use in each model. In the case of the CRED-Two Parameter Model (and also the other two models), no parameters for

Bulgaria were available. Therefore, a group of countries with presumably similar economic histories and development levels to Bulgaria were selected. It was decided that of the available options, that those from Kazakhstan, Russia and Ukraine could be used – particularly because of their geographic proximity to Bulgaria and because they all had the exact same parameters. This also had to be done when using the RICE model for Bulgaria, where values for the European Union as a whole were used as a proxy for Bulgaria, despite probable divergence of costs and existing efficiency levels across the EU. Finally, when deploying the EMF-22 Model, the parameters for the Annex 1 Parties to the United Nations Framework Convention on Climate Change were used, of which Bulgaria is included. While these proxy parameters may introduce some error into the cost calculations, this is an inherent problem in applying data from top-down macroeconomic cost models to smaller units of analysis.

Thirdly, when calculating the cost of the McKinsey basic renovation package according to each cost models, it was assumed that McKinsey accurately included every possible carbon abatement intervention and did so in the correct order according to cost. When using the cost models to calculate the cost of this intervention, each intervention was, in a sense, overlaid on each cost model, so that the costs where that particular residential refurbishment laid on the cost model curve could be calculated. If the McKinsey model did not include a particular intervention, or miscalculated the costs of a particular intervention, then these calculations will be incorrect.

Fourthly, when trying to locate real case-based data to gain insights into the costs and benefits of energy efficiency interventions, there were limitations on the number of cases where raw data could be found. Since such data was only located for three buildings, there could be major discrepancies between these buildings and the costs and benefits for similar interventions on a national, regional, or even city-wide scale. While we were apprehensive about the generalizing from such a small number of cases, we felt that it could be useful in order to gain insights into what benefits such interventions could deliver to society if all earmarked funds were spent on this particular intervention. Also, the interventions undertaken in the STACCATO project were slightly more intensive than those proposed by the refurbishment package from McKinsey that was investigated within this study. As such, a one-to-one comparison of these two interventions could not be conducted and inferences into the differences and similarities between them had to be made in order to have any chance in draw conclusions from them.

Fifth, it is only possible to roughly approximate the financial outlays that are available for energy efficiency improvements in Bulgaria. The plethora of programs and funds that were identified for such measures all have different priorities, procedures, administrative overheads and timelines that make highly accurate estimations impossible. It is important to note this in understanding that the potential cutbacks from baseline that were estimated could be significantly different depending on the degree of error in these estimations.

Sixth, and finally, there are some issues with the data from the survey conducted within the PACITA project in that it was not necessarily representative of Bulgarian society and/or the viewpoints held by Bulgarian citizens. Thus, there could potentially be issues in using this data to support the conclusion that Bulgarian citizens (and many European citizens) might not want to consume less regardless or the reason, as well as to give evidence to the notion that the majority of Bulgarians do not want to change income based taxation to taxation on their consumption.

If this investigative approach was redesigned, arguably the most avoidable of these issues could be the low level of real case-based information. During the data aggregation phase, the Sofia Energy Agency was contacted in order to obtain available data on the costs and benefits of energy efficiency improvement in residential buildings. After meeting with their team, it was determined by the investigator that these three cases had the most robust data sets available and were used accordingly. It is possible that if better communication was made with governmental agencies and ministries, that more robust program-level data could be obtained from the evaluations of currently running or completed energy efficiency programmes with various abatement packages and approaches for comparison.

It is also possible that more accurate data pertaining to the available financial outlays for energy efficiency improvements in the country could be determined. However, the amount of effort needed to detangle the various funding lines and priorities in these instruments in order to determine the precise amount available for energy efficiency improvements in households may entail an entire study in and of themselves. Further, given that the priorities of multi-year funding programmes can change, and that the exact way that funding will be used, and the exact specifications of projects that it may be used on, may not yet be determined, this may be a fool’s errand to even attempt.

Taken altogether, we can infer that the hypothesis that energy efficiency improvements in residential buildings can deliver economic benefits to their residents is true. However, the economic effects of such improvements, at least in the actual case studies used here, were not as impressive as the cost models alluded to. This could result either from the relatively low costs of energy in Bulgaria compared to European Union average costs, higher than expected retrofitting costs, or a combination of the two. When looking at the retrofits delivered through the STACCATO project, it was calculated that nearly 50 years of retrofit functionality would be needed for that particular retrofit to meet the negative cost abatement predicted by the McKinsey cost curve – an impossible outcome.

On a more positive note, when applying the estimated amount of financing available for energy efficiency improvements to the three cost models, we find that deep emissions cutbacks are possible. While these macro-economic top-down models do not provide insight into the types of interventions necessary to achieve these cutbacks, they do open the door towards a deeper investigation about what these opportunities might be. Herein, we speculate that such low-hanging fruits can be captured by less invasive energy efficiency interventions as a starting point. The fight against climate change will require many different levers in order to reduce negative human impacts on the environment at the same time as qualities of life around the world continually increase. Finding those options which are cost-optimizing is an important first step in sawing through the Gordian Knot of political inaction in addressing climate change.

Scientific studies which document species extinctions, the melting of polar ice sheets and increasingly erratic weather patterns all are important. They pile on additional evidence of the negative impacts of human activities on the natural environment. Attempts to study and “save” individual species from extinction, provide asylum for environmental migrants, and efforts to clean up specific polluted areas of land, water and air are all heroic acts. But at a global scale, they could be paralleled, as the adage goes, to rearranging the deck chairs on the Titanic. Eating locally grown food, reducing the consumption of animal products and taking public transportation instead of using personal vehicles all contribute to a slowdown of atmospheric carbon concentrations and the future temperature rises that result from this.

One issue with analysing the potential of individual abatement options is that it may give the impression that discrete options can break-though the momentum of years of inadequate action on climate change. In aggregate, it is possible that they can have an impact. This way of thinking about individual options is inherent in the scientifically reductionist way of analysing a particular phenomenon, and is the approach that was undertaken within this study to better understand the potential for building envelope refurbishments to deliver economic and environmental goods. However, as world-renowned economist Jeffery Sachs said in a recent interview "If China and India continue to completely depend on coal as they are…if it's true that the major parts of the world don't participate, then it does not matter what you and I do and that is why we need a global understanding and a global agreement."[95]

[95] Interview with Dr. Jeffrey Sachs, CNN – Global Public Square, April 19th, 2015.

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Annex 1 – McKinsey Values for Calculating Residential Retrofits

								2015	2020
Abatement Cost	Net incremental costs	Cumulative Annualized incremental Capex	Difference in Price by Area	Cost of New Technology (EUR/Unit)				3.66	3.66
				Cost of Reference Technology (EUR/Unit)				0	0
			HVAC Volume Needed Each Year	HVAC Volume Needed Each Year (Million m2)				431.10	862.19
		Opex	Opex Savings from Direct Energy	Cost of Direct Energy (EUR/MWh)				18.55	21.09
				Savings Direct Energy Consumption (MWh)				15.40	27.34
			Opex Savings from Indirect Energy	Cost of Indirect Energy EUR/MWh				51.13	55.56
				Savings Indirect Energy Consumption MWh				.25	.12
	Abatement Volume MtCO2e	Direct abatement MtCO2e	Savings Direct energy consumption MWh	Share of direct energy consumption HVAC (%)				1540	2734
				Cumulative savings total energy consumption MWh	Effective floor space for retrofit (Million M2)	Incremental share (%)	Implementation share in abatement case (%)	24	46
							Implementation share in	3	4

							reference case (%)		
						Existing 2005 floor space available for retrofit (Million m2)		2052.84	2052.84
					Energy savings per unit area (KwH/m2)	Energy consumed per unit area of reference technology (Kwh/m2)		145.22	127.39
						Energy consumed per unit area of new technology (Kwh/m2)		108.92	95.54
			Emissions intensity, direct fuel					.24	.25
		Indirect abatement MtCO2e	Savings Indirect energy consumption (MWh)	Cumulative savings total energy consumption MWh	Effective floor space for retrofit (Million m2)	Incremental Share (%)	Implementation share in abatement case (%)	24	46
							Implementation share in reference case (%)	3	4
						Existing 2005 floor space available for retrofit (Million m2)		2052.84	2052.84
					Energy savings per unit area (kWh/m2)	Energy consumed per unit area of reference technology (Kwh/m2)		145.22	127.39

						Energy consumed per unit area of new technology (Kwh/m2)		108.92	95.54
				Share of indirect electricity consumption HVAC (%)				2	0
			Emissions intensity electricity (tCO2e/MWh)					.42	.3

Annex 2 – Construction of Carbon Abatement Cost Curve for Bulgaria in R

```
f <- data.frame(x = c("Water Heating", "Lighting LED - Residential", "Behavioral", "Improved Maintenance", "Planning", "Electronics consumer - residential", "Electronics office - commercial", "Retrofit - building envelope - commercial", "Retrofit HVAC - controls - commercial", "Motor systems - new build", "Retrofit HVAC - commercial", "Energy efficiency projects CapEx", "More energy efficient new builds in upstream", "LDV - gasoline bundle 3", "Appliances - residential", "LDV - diesel bundle 3 ", "Retrofit HVAC - electric resistance heating to electric heat pump - residential", "1st generation bio-fuels", "LDV - diesel bundle 4", "LDV - gasoline bundle 4", "LDV - gasoline Full Hybrids", "2nd generation bio-fuels", "Co-generation - retrofit", "Co-generation - new build", "Efficiency package - new build, commercial", "Efficiency package - new build, residential", "CHP - new build", "LDV - gasoline Plug-in Hybrids", "Retrofit HVAC - gas/oil heating - residential", "LDV - diesel Full Hybrids", "Direct casting - new build", "Retrofit - building envelope - residential", "HDV - diesel bundle 4", "Cropland nutrient management", "Retrofit HVAC - maintenance - residential", "Landfill gas direct use", "LDV - diesel plug-in hybrids", "Other industry", "Alternative fuels - waste", "Livestock - antimethanogen vaccine", "Replace seals", "Landfill gas electricity generation", "Tillage and residue management practices", "Retrofit - building envelope package 2 - residential", "Clinker substitution by slag", "Maintain compressors", "Distribution maintenance", "Recycling new waste", "Small hydro", "Process intensification - process - level 1", "Catalyst optimization - process - level 1", "Grassland management", "N2O decomposition of nitric acid - new build", "Nuclear", "Energy efficiency 1 - general", "Organic soils restoration", "Composting new waste", "Degraded land restoration", "Agronomy practices", "N2O decomposition of nitric acid - retrofit", "Gas CCS - retrofit", "Pastureland afforestation", "Smelt reduction - retrofit", "Smelt reduction - new build", "Degraded forest reforestation", "Forest management", "Catalyst optimization - process - level 2", "Coal CCS - retrofit", "Water heating - replacement of electric - residential", "Energy efficiency 2 - general", "Coke substitution - new build", "Coke substitution - retrofit", "Catalyst optimization - process - level 3", "CCS - new build", "CCS ammonia - new build", "CCS direct energy - new build", "CCS - retrofit", "Carbon capture and storage in downstream operations", "CCS ammonia - retrofit", "CCS direct energy - retrofit", "Livestock feed supplements", "Biomass - co-firing"), width = c(.3164, .0791, .0791, .0791, .0791, .2373, .0791, .4746, .1582, .1582, .2373, .1582, .2373, .1582, .3955, .0791, .2373, .0791, .4746, .3955, .1582, .0791, .0791, .1582, .3164, 2.3732, .0791, .1582, .0791, .1582, .0791, .8701, .0791, .7910, .0791, .7119, .0791, .8701, .0791, .3164, .0791, 1.2657, .3955, 2.6105, .3164, .2373, .6328, .1582, 4.5091, .0791, .0791, .7119, .1582, 4.5882, .3955, .6328, .3164, .1582, .9492, .1582, .0791, .8701, .0791, .1582, 1.1075, .2373, .0791, .0791, .1582, .2373, .2373, .1582, .0791, 1.2657, .0791, .0791, 1.18662, .2373, .2373, .1582, .1582, .0791), height = c(-163.55100, -152.74, -148.05, -146.16, -145.44, -137.32, -137.32, -131.8, -129.83, -112.59, -112.56, -109.77, -106.55, -106.36, -105.93, -100.71, -100.46, -100.42, -100.23, -100.15, -95.31, -89.86, -84.38, -84.11, -76.74, -70, -69.76, -65.5, -63.28, -62.12, -59.59, -56.87, -46.74, -45.18, -44.47, -38.01, -36.58, -34.27, -29.24, -26.06, -26.06, -24.41, -23.12, -21.74, -20.87, -19.86, -14.87, -8.89, -7.49, 0, 0, 2.14, 4.4, 4.87, 6.16, 6.76, 7.27,
```

```
7.5, 8.76, 8.79, 9.26, 9.48, 11.37, 11.82, 15.77, 16.41, 19.35, 21.06, 24.41,
31.36, 33.88, 33.91, 38.7, 43.26, 49.23, 49.31, 51.02, 51.02, 54.98, 54.99,
64.35, 75.08))
df$w <- cumsum(df$width)
df$wm <- df$w - df$width
df$wt <- with(df, wm + (w - wm)/2)
library(ggplot2)
p <- ggplot(df, aes(ymin = 0)) + xlab("Carbon Abatement Potential in Bulgaria
\n MtCO2e") + ylab("Cost per ton of Abatement \n Euro")
p1 <- p + geom_rect(aes(xmin = wm, xmax = w, ymax = height, fill = x))
p1 + theme(legend.position = "none") + ggtitle("Marginal Abatement Cost Curve
\n- Bulgaria") + theme(plot.title = element_text(lineheight=.7, face="bold"))
p2 <- p1 + geom_text(aes(x = wt, y = height * 0.5, label = x, size = .001,
angle = 90))
p2 + theme_bw() + theme(legend.position = "none") + labs(x = NULL, y = NULL)
+ xlab("Abatement Potential in Bulgaria \n MtCO2e") + ylab("Cost per Ton of
Abatement \n Euro") + ggtitle("Marginal Abatement Cost Curve - Bulgaria
\nBased on McKinsey Data") + theme(plot.title = element_text(lineheight=.7,
face="bold"))
```

Annex 3 – Costs for Residential Envelope Refurbishments Using Rice and EMF-22 Models

At this abatement level in GtC	At his abatement level in GtCO2	Percentage Carbon Reduction from Business as Usual	Cost as a Percentage of GDP - RICE	Cost as a Percentage of GDP - EMF-22
0	0	0.00000%	0.00%	0.00%
0.001	0.00367	7.56763%	0.00%	0.07%
0.002	0.00734	15.13527%	0.02%	0.20%
0.003	0.01101	22.70290%	0.05%	0.36%
0.004	0.01468	30.27054%	0.12%	0.54%
0.005	0.01835	37.83817%	0.22%	0.75%
0.006	0.02202	45.40581%	0.37%	0.98%
0.007	0.02569	52.97344%	0.57%	1.23%
0.008	0.02936	60.54108%	0.83%	1.49%
0.009	0.03303	68.10871%	1.16%	1.77%
0.01	0.03726	74.91958%	1.51%	2.04%
0.011	0.04037	83.24398%	2.03%	2.37%
0.012	0.04404	90.81161%	2.60%	2.69%
0.013	0.04771	98.37925%	3.25%	3.03%
0.013214169	0.048496	100.00000%	3.40%	3.10%

	in GtC	Percentage Carbon Reduction from BAU	Cost as a Percentage of GDP - RICE	Cost as a Percentage of GDP - EMF-22
Upper Value Building Retrofit Residential (UV)	0.002392648	18.11%	0.0284%	0.2571%
Lower Value Building Retrofit Residential (LV)	0.00215553	16.31%	0.0212%	0.2208%
UV-LV (in %) - Percentage of GDP to Executure Building Retrofit			0.0072%	0.0363%
Cost in 2005 USD for Building Envelope Retrofit			$5,335,913.71	$26,879,744.66

Annex 4 – Years to Achieve Similar Average Costs to McKinsey

Year	tCO_2 abated	Cumulative. Savings (€)	Cumulative Benefit After Renovation Cost (€)	Cost Per tCO2 abated in Each Year (€)	Average Cost Per tCO2 abated (€)
1	1	461.04	3781.66	3781.66	3781.66
2	2	922.08	3320.62	1660.31	2720.99
3	3	1383.12	2859.58	953.19	2131.72
4	4	1844.16	2398.54	599.64	1748.70
5	5	2305.2	1937.5	387.50	1476.46
6	6	2766.24	1476.46	246.08	1271.40
7	7	3227.28	1015.42	145.06	1110.49
8	8	3688.32	554.38	69.30	980.34
9	9	4149.36	93.34	10.37	872.57
10	10	4610.4	-367.7	-36.77	781.63
11	11	5071.44	-828.74	-75.34	703.73
12	12	5532.48	-1289.78	-107.48	636.13
13	13	5993.52	-1750.82	-134.68	576.83
14	14	6454.56	-2211.86	-157.99	524.35
15	15	6915.6	-2672.9	-178.19	477.51
16	16	7376.64	-3133.94	-195.87	435.42
17	17	7837.68	-3594.98	-211.47	397.37
18	18	8298.72	-4056.02	-225.33	362.78
19	19	8759.76	-4517.06	-237.74	331.17
20	20	9220.8	-4978.1	-248.91	302.17
21	21	9681.84	-5439.14	-259.01	275.44
22	22	10142.88	-5900.18	-268.19	250.73
23	23	10603.92	-6361.22	-276.57	227.81
24	24	11064.96	-6822.26	-284.26	206.47
25	25	11526	-7283.3	-291.33	186.56
26	26	11987.04	-7744.34	-297.86	167.93
27	27	12448.08	-8205.38	-303.90	150.45
28	28	12909.12	-8666.42	-309.52	134.02
29	29	13370.16	-9127.46	-314.74	118.55
30	30	13831.2	-9588.5	-319.62	103.94
31	31	14292.24	-10049.54	-324.18	90.13
32	32	14753.28	-10510.58	-328.46	77.05
33	33	15214.32	-10971.62	-332.47	64.64
34	34	15675.36	-11432.66	-336.25	52.85
35	35	16136.4	-11893.7	-339.82	41.63

36	*36*	*16597.44*	*-12354.74*	*-343.19*	*30.94*
37	*37*	*17058.48*	*-12815.78*	*-346.37*	*20.75*
38	*38*	*17519.52*	*-13276.82*	*-349.39*	*11.01*
39	*39*	*17980.56*	*-13737.86*	*-352.25*	*1.69*
40	*40*	*18441.6*	*-14198.9*	*-354.97*	*-7.23*
41	*41*	*18902.64*	*-14659.94*	*-357.56*	*-15.77*
42	*42*	*19363.68*	*-15120.98*	*-360.02*	*-23.97*
43	*43*	*19824.72*	*-15582.02*	*-362.37*	*-31.84*
44	*44*	*20285.76*	*-16043.06*	*-364.62*	*-39.40*
45	*45*	*20746.8*	*-16504.1*	*-366.76*	*-46.67*
46	*46*	*21207.84*	*-16965.14*	*-368.81*	*-53.68*
47	*47*	*21668.88*	*-17426.18*	*-370.77*	*-60.42*
48	*48*	*22129.92*	*-17887.22*	*-372.65*	*-66.93*
49	*49*	*22590.96*	*-18348.26*	*-374.45*	*-73.20*
50	*50*	*23052*	*-18809.3*	*-376.19*	*-79.26*