

TECHNOLOGICAL DETAILED MODELING AND ANALYSIS OF  
ELECTRICAL ENERGY USE AND CO<sub>2</sub> EMISSIONS IN TURKEY  
WITHIN THE FRAMEWORK OF MARKAL BASED BOTTOM-UP  
NATIONAL ENERGY MODEL

by

Kadriye Büşra Yılmaz

B.S., Mathematical Engineering, Yıldız Technical University, 2008

Submitted to the Institute for Graduate Studies in  
Science and Engineering in partial fulfillment of  
the requirements for the degree of  
Master of Science

Graduate Program in Industrial Engineering

Boğaziçi University

2013

## ACKNOWLEDGEMENTS

First and foremost, I would like to express deepest gratitude to my supervisor Prof. İlhan OR, for his patience, guidance, and insights that made this thesis possible. It is a great opportunity to do my thesis under his guidance.

I am grateful to my friend, Ömer Onur Kaya for providing me with an incredible support. Also I am deeply indebted to Faruk Cirit and Nihan Karali for their contributions and assistance. Besides, I would like to acknowledge Assoc. Prof. Umut Rıfat Tuzkaya and Assoc. Prof. İhsan Kaya for encouraging me during my thesis and thank TÜBİTAK for the financial and generous support. I also appreciate the tremendous support I have received over the years from my friends, administrators and staff at Boğaziçi University.

Finally, I would like to thank my family for lifting me out of my most difficult moments and encouraging me. None of this would have been possible without the love and patience of my family.

## ABSTRACT

### **TECHNOLOGICAL DETAILED MODELING AND ANALYSIS OF ELECTRICAL ENERGY USE AND CO<sub>2</sub> EMISSIONS IN TURKEY WITHIN THE FRAMEWORK OF MARKAL BASED BOTTOM-UP NATIONAL ENERGY MODEL**

In Turkey, as a fast developing country, demand for energy is growing each day. As energy's strategic importance regarding sustainable economic growth, social and political stability gets greater; an energy modeling system that balances long and short term energy supply and demand, identifies possible bottlenecks, coordinates investments and financing, and foresees environmental impacts, a scenario based framework becomes inevitable. For the purpose of analyzing and better understanding the energy sector of Turkey and being able to predict how the energy sector will evolve in the future; a "bottom-up", long-term energy supply and demand balance modeling system which is the "MARKAL" modeling system and the MARKAL-TURKEY model developed at Boğaziçi University are deployed in this study. Especially, the electricity generation sector of the MARKAL-Turkey model is analyzed and expanded with the aim of minimizing total costs and estimating total amount of greenhouse gas (GHG) emissions. Firstly, a reference scenario that reflects the status of Turkey's energy system under current conditions and expected future trends is generated, and different "What-if" scenarios are developed by, (i) restricting CO<sub>2</sub> emissions at a certain percentage, (ii) applying tax per tonne of CO<sub>2</sub>, (iii) changing fuel prices, (iv) forcing carbon capture and storage (CCS) technologies deployment and, (v) utilizing nuclear power. Together with the reference scenario, different realizations of these considerations and their combinations have led to the generation of a total of 30 scenarios (as the reference scenario and alternative scenarios). Finally, the results of each scenario are presented considering the electricity sector costs, the CO<sub>2</sub> emissions and fuel consumptions. After the analyses of these results, concluding remarks are given.

## ÖZET

### MARKAL ULUSAL ENERJİ MODELİ ÇERÇEVESİNDE TÜRKİYE’DE ELEKTRİK ENERJİSİ KULLANIMININ VE CO<sub>2</sub> SALIMININ TEKNOLOJİ DETAYLI MODELLENMESİ VE ANALİZİ

Gelişmekte olan bir ülke olarak, Türkiye’de enerjiye olan talep her geçen gün daha da artmaktadır. Sürdürülebilir ekonomik büyüme, sosyal ve politik istikrar konularında enerjinin stratejik değeri arttıkça, uzun ve kısa vadeli enerji arz-talep dengesini sağlayan, olası darboğazları tanımlayan, yatırım ve finansmanları koordine eden ve çevresel etkileri öngören senaryo tabanlı bir enerji modelleme sistemi önem kazanmaktadır. Bu çalışmada, Türkiye’nin enerji sektörünü daha iyi anlamak ve analiz etmek amacıyla, ayrıca enerji sektörünün gelecekte nasıl gelişeceğini tahmin edebilmek için, uzun vadeli bir enerji arz-talep dengesi modelleme sistem olan “MARKAL” modelleme sistemi ve Boğaziçi Üniversitesi’nde geliştirilen MARKAL-TÜRKİYE modeli uygulanmıştır. MARKAL-TÜRKİYE modelinin özellikle elektrik üretim sektörü ile ilgili modülleri üstüne odaklanılmış, bu sektörün toplam maliyetlerini minimize etmek ve toplam sera gazı emisyonlarının miktarını belirlemek amacıyla ilgili MARKAL-TÜRKİYE modülleri güncellenmiş ve genişletilmiştir. Öncelikle, Türkiye’nin enerji sistemini gerçeklikle yansıtan bir baz senaryo hazırlanmıştır, ve sonrasında ise, (i) karbondioksit emisyonunun belli bir oranda azaltıldığı, (ii) salınan karbondioksite birim ton başına vergi uygulandığı, (iii) yakıt maliyetlerinin arttırıldığı, (iv) karbon tutma ve yakalama teknolojilerinin uygulandığı ve (v) nükleer gücün kullanıldığı alternatif senaryolar üretilmiştir. Bu senaryolar ve kombinasyonlarıyla beraber; bir tanesi baz olmak üzere toplam 30 tane senaryo türetilmiştir. Her bir senaryonun maliyeti, salınan karbondioksit emisyonları ve yakıt tüketimleri ile ilgili sonuçlar sunulmuştur. Son olarak da, bu sonuçlar analiz edilmiş ve bir değerlendirmesi sunulmuştur.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS .....	iii
ABSTRACT.....	iv
ÖZET .....	v
LIST OF FIGURES .....	ix
LIST OF TABLES.....	xiii
LIST OF SYMBOLS .....	xx
LIST OF ACRONYMS/ABBREVIATIONS.....	xxi
1. INTRODUCTION .....	1
2. THE MARKAL MODELLING FRAMEWORK FOR ENERGY SYSTEMS.....	4
2.1. The MARKAL Energy Modeling System .....	4
2.2. Mathematical Formulation of the MARKAL Model.....	6
2.2.1. Decision Variables.....	7
2.2.2. The Objective Function .....	8
2.2.3. Constraints .....	10
2.2.3.1. Satisfaction of Demands.. .....	10
2.2.3.2. Capacity Transfer.....	10
2.2.3.3. Use of Capacity.....	11
2.2.3.4. Energy Balance.. .....	11
2.2.3.5. Emission Constraint or Emission Tax. ....	12
2.2.3.6. Electricity Baseload Constraints.....	12
2.2.3.7. Electricity and Heat Energy Peak Reserve Constraints. ....	13
2.3. The MARKAL-Turkey Model.....	14
3. LITERATURE SURVEY.....	17

3.1. Research in Energy Modeling Systems and Electricity Generation .....	17
3.2 Some Key Global and Local Energy Statistics .....	20
3.2.1. Energy Outlook in the World.....	20
3.2.2. Energy Outlook in Turkey .....	25
3.2.3. Electricity Outlook in the World .....	28
3.2.4. Electricity Outlook in Turkey .....	29
3.2.5. Environmental Impacts of the Energy Sector in the World.....	31
3.2.6. Environmental Impacts of the Energy Sector in Turkey .....	33
4. A DETAILED MARKAL MODEL OF THE TURKISH ELECTRCITY SECTOR .....	35
4.1. Hydro Energy .....	36
4.2. Wind Energy .....	37
4.3. Geothermal Energy .....	39
4.4. Solar Energy .....	41
4.5. Bio-Power energy.....	42
4.6. Nuclear Power .....	43
4.7. Hydrogen Energy .....	44
4.8. Coal .....	45
4.9. Heavy Fuel Oil .....	47
4.10. Natural Gas.....	47
5. SCENARIOS AND THEIR RESULTS .....	50
5.1. The Base Scenario .....	50
5.2. Alternative Scenarios .....	56
5.2.1. The Emission Restriction Scenarios .....	56
5.2.2. The Nuclear Scenarios .....	62
5.2.3. The CCS Scenarios .....	67

5.2.4. The Tax Scenarios .....	73
5.2.5. The Fuel Price Increase Scenarios .....	80
5.2.6. The Emission Restriction and Tax Scenario .....	86
5.2.7. The Emission Restriction and Fuel Price Increase Scenario .....	89
5.2.8. The Fuel Price Increase and Emission Tax Scenario .....	92
5.2.9. The Emission Restriction, Fuel Price Increase and Tax Scenario .....	95
5.2.10. The Nuclear and Emission Tax Scenario .....	98
5.2.11. The Nuclear and Fuel Price Increase Scenario .....	101
5.2.12. The Fast Nuclear, Fuel Price Increase and Emission Tax Scenario .....	104
5.2.13. The Emission Restriction and Nuclear Scenario .....	107
5.2.14. The Nuclear, Emission Restriction and Tax Scenario .....	110
5.2.15. The Nuclear, Emission Restriction and Fuel Price Increase Scenario .....	113
5.2.16. The Nuclear, Emission Restriction, Fuel Price Increase and Emission Tax Scenario .....	115
5.2.17. The CCS and Tax Scenario .....	117
5.2.18. The CCS and Fuel Price Increase Scenario .....	120
5.2.19. The CCS, Fuel Price Increase and Tax Scenario .....	123
5.2.20. The CCS and Emission Restriction Scenario .....	126
5.2.21. The CCS, Emission Restriction and Tax Scenario .....	128
5.2.22. The CCS, Emission Restriction and Fuel Price Increase Scenario .....	131
5.2.23. The CCS, Fuel Price Increase, Emission Restriction and Tax Scenario .....	133
6. CONCLUSION .....	136
APPENDIX A: TECHNOLOGICAL DETAILS IN THE BASE SCENARIO .....	145
APPENDIX B: TOTAL CO <sub>2</sub> EMISSIONS BY TECHNOLOGIES .....	148
APPENDIX C: THE LIST OF SCENARIOS .....	150
REFERENCES .....	151

## LIST OF FIGURES

Figure 2.1. Partial view of a simple Reference Energy System [9].....	6
Figure 2.2. Baseload, reserve capacity and peak [9]. .....	14
Figure 2.3. A simplified representation of MARKAL-Turkey model components [5].....	16
Figure 3.1. World primary energy consumption [25]. .....	21
Figure 3.2. World primary energy consumption by fuel types in 2011 [25]. .....	22
Figure 3.3. Total primary energy supply in the World [27]. .....	23
Figure 3.4. Fuel shares of total final energy consumption in the World in 1973 [27].....	23
Figure 3.5. Fuel shares of total final energy consumption in the World in 2009 [27].....	24
Figure 3.6. Total primary energy supply in Turkey [30]. .....	27
Figure 3.7. World electricity generation by source of energy Terawatt-hours (TWh) [31]. .....	28
Figure 3.8. Turkey's electricity generation by fuels in 2008 [33].....	30
Figure 3.9. World (OECD and non-OECD) CO <sub>2</sub> emissions (1965-2011) [25]. .....	31
Figure 3.10. Primary energy resource shares in CO <sub>2</sub> emissions in the World in 1973 [27]. .....	32
Figure 3.11. Primary energy resource shares in CO <sub>2</sub> emissions in the World in 2009 [27]. .....	32
Figure 3.12. Breakdown of GHG emissions within the energy sector in 1990 [35]. .....	33
Figure 3.13. Breakdown of GHG emissions within the energy sector in 2010 [35]. .....	33
Figure 4.1. The installed capacity for wind energy from 1998 to 2010 in Turkey [44]. ....	39
Figure 4.2. World coal consumption (Mtoe, percentage) [33]. .....	45
Figure 5.1. Total CO <sub>2</sub> emissions of all sectors in the BASE and the BAUSOLF scenarios. ....	51
Figure 5.2. Costs of the electricity sector in the BASE scenario (M pounds). .....	51

Figure 5.3. Costs of the electricity sector in the BAUSOLF scenario (M pounds).....	52
Figure 5.4. Costs of all sectors in the BASE scenario (M pounds). .....	52
Figure 5.5. Costs of all sectors in the BAUSOLF scenario (M pounds). .....	53
Figure 5.6. CO <sub>2</sub> Emissions of the electricity sector in the RS_C_20 scenario. ....	60
Figure 5.7. CO <sub>2</sub> Emissions of the electricity sector in the RS_C_40 scenario. ....	60
Figure 5.8. Costs of the electricity sector in the RS_C_20 scenario (M pounds).....	61
Figure 5.9. Costs of the electricity sector in the RS_C_40 scenario (M pounds).....	62
Figure 5.10. CO <sub>2</sub> Emissions of the electricity sector in the RS_NUCF scenario. ....	65
Figure 5.11. CO <sub>2</sub> Emissions of the electricity sector in the RS_NUCS scenario. ....	66
Figure 5.12. Costs of the electricity sector in the RS_NUCF scenario (M pounds).....	66
Figure 5.13. Costs of the electricity sector in the RS_NUCS scenario (M pounds).....	67
Figure 5.14. CO <sub>2</sub> Emissions of the electricity sector in the RS_CCSL scenario.....	70
Figure 5.15. CO <sub>2</sub> Emissions of the electricity sector in the RS_CCSH scenario. ....	71
Figure 5.16. Costs of the electricity sector in the RS_CCSH scenario (M pounds).....	71
Figure 5.17. Costs of the electricity sector in the RS_CCSL scenario (M pounds). ....	72
Figure 5.18. CO <sub>2</sub> Emissions of the electricity sector in the RS_TAX10 scenario.....	76
Figure 5.19. CO <sub>2</sub> Emissions of the electricity sector in the RS_TAX20 scenario. ....	77
Figure 5.20. CO <sub>2</sub> Emissions of the electricity sector in the RS_TAX40 scenario. ....	77
Figure 5.21. Costs of the electricity sector in the RS_TAX10 scenario (M pounds). ....	78
Figure 5.22. Costs of the electricity sector in the RS_TAX20 scenario (M pounds). ....	78
Figure 5.23. Costs of the electricity sector in the RS_TAX40 scenario (M pounds). ....	79
Figure 5.24. CO <sub>2</sub> Emissions of the electricity sector in the RS_FP40 scenario. ....	83
Figure 5.25. CO <sub>2</sub> Emissions of the electricity sector in the RS_FP80 scenario. ....	84
Figure 5.26. Costs of the electricity sector in the RS_FP40 scenario (M pounds).....	85
Figure 5.27. Costs of the electricity sector in the RS_FP80 scenario (M pounds).....	85

Figure 5.28. CO <sub>2</sub> Emissions of the electricity sector in the C_40TAX2 scenario.....	88
Figure 5.29. Costs of the electricity sector in the C_40TAX2 scenario (M pounds). .....	88
Figure 5.30. CO <sub>2</sub> Emissions of the electricity sector in the C_40FP80 scenario. ....	91
Figure 5.31. Costs of the electricity sector in the C_40FP80 scenario (M pounds). .....	92
Figure 5.32. CO <sub>2</sub> Emissions of the electricity sector in the FP80TAX2 scenario.....	94
Figure 5.33. Costs of the electricity sector in the FP80TAX2 scenario (M pounds).....	95
Figure 5.34. CO <sub>2</sub> Emissions of the electricity sector in the C4FP80T2 scenario. ....	97
Figure 5.35. Costs of the electricity sector in the C4FP80T2 scenario (M pounds).....	98
Figure 5.36. CO <sub>2</sub> Emissions of the electricity sector in the NUCFTAX2 scenario.....	100
Figure 5.37. Costs of the electricity sector in the NUCFTAX2 scenario (M pounds). ....	101
Figure 5.38. CO <sub>2</sub> Emissions of the electricity sector in the NUCFFP80 scenario. ....	103
Figure 5.39. Costs of the electricity sector in the NUCFFP80 scenario (M pounds). ....	104
Figure 5.40. CO <sub>2</sub> Emissions of the electricity sector in the NFP80T2 scenario.....	106
Figure 5.41. Costs of the electricity sector in the NFP80T2 scenario (M pounds). ....	107
Figure 5.42. CO <sub>2</sub> Emissions of the electricity sector in the C_40NUCF scenario. ....	109
Figure 5.43. Costs of the electricity sector in the C_40NUCF scenario (M pounds). ....	110
Figure 5.44. CO <sub>2</sub> Emissions of the electricity sector in the C4NFT2 scenario. ....	112
Figure 5.45. Costs of the electricity sector in the C4NFT2 scenario (M pounds).....	112
Figure 5.46. CO <sub>2</sub> Emissions of the electricity sector in the C4NFFP80 scenario. ....	114
Figure 5.47. Costs of the electricity sector in the C4NFFP80 scenario (M pounds).....	115
Figure 5.48. CO <sub>2</sub> Emissions of the electricity sector in the C4NFF8T2 scenario.....	117
Figure 5.49. Costs of the electricity sector in the C4NFF8T2 scenario (M pounds).....	117
Figure 5.50. CO <sub>2</sub> Emissions of the electricity sector in the CCSHT2 scenario.....	119
Figure 5.51. Costs of the electricity sector in the CCSHT2 scenario (M pounds). ....	120
Figure 5.52. CO <sub>2</sub> Emissions of the electricity sector in the CCSHFP80 scenario.....	122

Figure 5.53. Costs of the electricity sector in the CSHFP80 scenario (M pounds). .....	123
Figure 5.54. CO <sub>2</sub> Emissions of the electricity sector in the CHFP80T2 scenario. ....	125
Figure 5.55. Costs of the electricity sector in the CHFP80T2 scenario (M pounds). ....	125
Figure 5.56. CO <sub>2</sub> Emissions of the electricity sector in the C_40CCSH scenario. ....	127
Figure 5.57. Costs of the electricity sector in the C_40CCSH scenario (M pounds). ....	128
Figure 5.58. CO <sub>2</sub> Emissions of the electricity sector in the C4CCSHT2 scenario. ....	130
Figure 5.59. Costs of the electricity sector in the C4CCSHT2 scenario (M pounds). ....	130
Figure 5.60. CO <sub>2</sub> Emissions of the electricity sector in the C4CHFP80 scenario. ....	132
Figure 5.61. Costs of the electricity sector in the C4CHFP80 scenario (M pounds). ....	133
Figure 5.62. CO <sub>2</sub> Emissions of the electricity sector in the C4CHF8T2 scenario. ....	135
Figure 5.63. Costs of the electricity sector in the C4FP80T2 scenario (M pounds). ....	135

## LIST OF TABLES

Table 3.1. World primary energy consumptions by regions (Million Tons of Oil Equivalent (Mtoe)) [25]. .....	22
Table 3.2. A comparison of socio-economic, energy and carbon data for OECD countries and the World in 2008 [28]. .....	24
Table 3.3. A Comparison of Turkey's socio-economic, energy and carbon indicators for 1990-2008 [28]. .....	25
Table 3.4. Primary Energy Resource Production [29]. .....	26
Table 3.5. Primary Energy Resource Consumption [29]. .....	26
Table 3.6. Energy Consumption by Sectors (Thousand Tons of Oil Equivalent (KToe))[29]. .....	28
Table 3.7. Electricity energy production by resources in Turkey[32]. .....	29
Table 3.8. CO <sub>2</sub> emissions from the energy and electricity sectors in Thousand Tonnes (kt) [34]. .....	30
Table 3.9. Turkey's Gross-Net Electricity Production, Import, Gross Electricity Consumption, Grid Losses and Export (GWh) from 2006 to 2010 [29]. .....	30
Table 3.10. Total greenhouse gas emissions by sectors in Turkey (1990-2009) [28]. .....	34
Table 4.1. The share of hydro electricity generation over total electricity generation (GWh) [32]. .....	36
Table 4.2. The technical and economic potential of Turkey's hydro electricity generation in 2010 [32]. .....	37
Table 4.3. Wind power potential [44]. .....	38
Table 4.4. The installed geothermal power capacity (MW) for Turkey and World (1975-2011) [25]. .....	40
Table 4.5. Average solar energy potential of Turkey and insolation durations on monthly basis [56]. .....	42

Table 4.6. Renewable Resources in Turkey (2011) [44].	42
Table 4.7. Planned and proposed nuclear power reactors [68].	44
Table 4.8. The shares of resources in total energy consumption between 1975 and 2010 in Turkey (%) [80].	48
Table 5.1. Energy consumptions of the all sectors by resources in the BAUSOLF scenario (PJ).	53
Table 5.2. Share of energy consumptions in all sectors by resources in the BAUSOLF scenario (%).	54
Table 5.3. Energy consumptions of all sectors by resources in the BASE scenario (PJ).	54
Table 5.4. Share of energy consumptions in all sectors by resources in the BASE scenario (%).	54
Table 5.5 Energy consumptions of the electricity sector by resources in the BASE scenario (PJ).	55
Table 5.6. Share of energy consumptions in the electricity sector by resources in the BASE scenario (%).	55
Table 5.7. The CO <sub>2</sub> emission bounds for the RS_C_20 and the RS_C_40 scenarios (kt).	57
Table 5.8. Energy consumptions of the electricity sector by resources in the RS_C_20 scenario (PJ).	57
Table 5.9. Share of energy consumptions in the electricity sector by resources in the RS_C_20 scenario (%).	58
Table 5.10. Energy consumptions of the electricity sector by resources in the RS_C_40 scenario (PJ).	59
Table 5.11. Share of energy consumptions in the electricity sector by resources in RS_C_40 scenario (%).	59
Table 5.12. Energy consumptions in the electricity sector by resources in the RS_NUCF scenario (PJ).	63
Table 5.13. Share of energy consumptions in the electricity sector by resources in the RS_NUCF scenario (%).	63

Table 5.14. Energy consumptions of the electricity sector by resources in the RS_NUCS scenario (PJ).....	64
Table 5.15. Share of energy consumptions in the electricity sector by resources in the RS_NUCS scenario (%). .....	64
Table 5.16. Energy consumptions of the electricity sector by resources in the RS_CCSL scenario (PJ). .....	68
Table 5.17. Share of energy consumptions in the electricity sector by resources in the RS_CCSL scenario (%). .....	68
Table 5.18. Energy consumptions of the electricity sector by resources in the RS_CCSH scenario (PJ). .....	69
Table 5.19. Share of energy consumptions in the electricity sector by resources in the RS_CCSH scenario (%). .....	69
Table 5.20. Energy consumptions of the electricity sector by resources in the RS_TAX10 scenario (PJ). .....	73
Table 5.21. Share of energy consumptions in the electricity sector by resources in the RS_TAX10 scenario (%). .....	74
Table 5.22. Energy consumptions of the electricity sector by resources in the RS_TAX20 scenario (PJ). .....	74
Table 5.23. Share of energy consumptions in the electricity sector by resources in the RS_TAX20 scenario (%). .....	74
Table 5.24. Energy consumptions of the electricity sector by resources in the RS_TAX40 scenario (PJ). .....	75
Table 5.25. Share of energy consumptions in the electricity sector by resources in the RS_TAX40 scenario (%). .....	75
Table 5.26. The tax results for each period in tax scenarios.....	79
Table 5.27. Energy consumptions of the electricity sector by resources in the RS_FP40 scenario (PJ). .....	81
Table 5.28. Share of energy consumptions in the electricity sector by resources in the RS_FP40 scenario (%). .....	81

Table 5.29. Energy consumptions of the electricity sector by resources in the RS_FP80 scenario (PJ).....	82
Table 5.30. Share of energy consumptions in the electricity sector by resources in the RS_FP80 scenario (%). .....	82
Table 5.31. Share of energy consumptions in the electricity sector by resources in the C_40TAX2 scenario (%). .....	87
Table 5.32. Share of energy consumptions in the electricity sector by resources in the C_40TAX2 scenario (%). .....	87
Table 5.33. Energy consumptions of the electricity sector by resources in the C_40FP80 scenario (PJ). .....	89
Table 5.34. Share of energy consumptions in the electricity sector by resources in the C_40FP80 scenario (%). .....	90
Table 5.35. Energy consumptions of the electricity sector by resources in the FP80TAX2 scenario (PJ). .....	93
Table 5.36. Share of energy consumptions in the electricity sector by resources in the FP80TAX2 scenario (%). .....	93
Table 5.37. Energy consumptions of the electricity sector by resources in the C4FP80T2 scenario (PJ). .....	96
Table 5.38. Share of energy consumptions in the electricity sector by resources in the C4FP80T2 scenario (%). .....	96
Table 5.39. Energy consumptions of the electricity sector by resources in the NUCFTAX2 scenario (PJ). .....	99
Table 5.40. Share of energy consumptions in the electricity sector by resources in the NUCFTAX2 scenario (%). .....	99
Table 5.41. Energy consumptions of the electricity sector by resources in the NUCFFP80 scenario (PJ). .....	102
Table 5.42. Share of energy consumptions in the electricity sector by resources in the NUCFFP80 scenario (%). .....	102

Table 5.43. Energy consumptions of the electricity sector by resources in the NFP80T2 scenario (PJ).....	105
Table 5.44. Share of energy consumptions in the electricity sector by resources in the NFP80T2 scenario (%)......	105
Table 5.45. Energy consumptions of the electricity sector by resources in the C_40NUCF scenario (PJ).....	108
Table 5.46. Share of energy consumptions in the electricity sector by resources in the C_40NUCF scenario (%). .....	108
Table 5.47. Energy consumptions of the electricity sector by resources in the C4NFT2 scenario (PJ). .....	111
Table 5.48. Share of energy consumptions in the electricity sector by resources in the C4NFT2 scenario (%). .....	111
Table 5.49. Share of energy consumptions in the electricity sector by resources in the C4NFFP80 scenario (%). .....	113
Table 5.50. Share of energy consumptions in the electricity sector by resources in the C4NFFP80 scenario (%). .....	113
Table 5.51. Energy consumptions of the electricity sector by resources in the C4NFF8T2 scenario (PJ).....	116
Table 5.52. Share of energy consumptions in the electricity sector by resources in the C4NFF8T2 scenario (%). .....	116
Table 5.53. Energy consumptions of the electricity sector by resources in the CCSHT2 scenario (PJ). .....	118
Table 5.54. Share of energy consumptions in the electricity sector by resources in the CCSHT2 scenario (%)......	118
Table 5.55. Energy consumptions of the electricity sector by resources in the CCSHF80 scenario (PJ). .....	121
Table 5.56. Share of energy consumptions in the electricity sector by resources in the CCSHF80 scenario (%)......	121

Table 5.57. Energy consumptions of the electricity sector by resources in the CHFP80T2 scenario (PJ).....	124
Table 5.58. Share of energy consumptions in the electricity sector by resources in the CHFP80T2 scenario (%). .....	124
Table 5.59. Energy consumptions of the electricity sector by resources in the C_40CCSH scenario (PJ). .....	126
Table 5.60. Share of energy consumptions in the electricity sector by resources in the C_40CCSH scenario (%). .....	126
Table 5.61. Energy consumptions of the electricity sector by resources in the C4CCSHT2 scenario (PJ).....	129
Table 5.62. Share of energy consumptions in the electricity sector by resources in the C4CCSHT2 scenario (%). .....	129
Table 5.63. Energy consumptions of the electricity sector by resources in the C4CHFP80 scenario (PJ). .....	131
Table 5.64. Share of energy consumptions in the electricity sector by resources in the C4CHFP80 scenario (%). .....	131
Table 5.65. Energy consumptions of the electricity sector by resources in the C4CHF8T2 scenario (PJ). .....	134
Table 5.66. Share of energy consumptions in the electricity sector by resources in the C4CHF8T2 scenario (%). .....	134
Table 6.1. The CO <sub>2</sub> emissions of the electricity sector by scenarios (kt). .....	136
Table 6.3. Electricity sector costs and CO <sub>2</sub> emissions by scenarios. ....	138
Table 6.5. Electricity sector cost increases by scenarios (sorted). .....	139
Table 6.7. Electricity sector CO <sub>2</sub> emissions and reduction rate (sorted). .....	141
Table 6.8. Electricity sector CO <sub>2</sub> emissions, total CO <sub>2</sub> emissions of all sectors by scenarios. ....	143
Table 6.9. The tax amounts for each period by applied tax scenarios. ....	144

Table A.1. Availability, fix and variable O&M costs and installed power of electricity technologies in the BASE scenario. ....	145
Table B.1. CO <sub>2</sub> emission coefficient (for all sectors) per activity in the BASE scenario for resource technologies (kt/PJ).....	148
Table B.2. CO <sub>2</sub> emission coefficient (for all sectors) per activity in the BASE scenario for conversion or process technologies (kt/PJ). ....	149
Table C.1. The list of generated scenarios.....	150

## LIST OF SYMBOLS

BkWh	Billion Kilowatt Hours
GW	Giga-Watt
GWh	Giga-Watt Hours
Kcal	Kilocalorie
km <sup>2</sup>	Square Kilometre
Kt	Thousand Tons
KToe	Thousand Tons of Oil Equivalent
KWh	Kilowatt Hour
m	Metre
Mtoe	Million Tons of Oil Equivalent
Mton	Million Tonnes
Mton CO <sub>2</sub> e	Million Tons of Carbon Dioxide Equivalent
MW	Megawatt
MWe	Megawatt Electrical
MWt	Mega Watt Thermal
TWh	Terawatt-hours
US\$	United States Dollar
W	Watt

## LIST OF ACRONYMS/ABBREVIATIONS

AP1000 (URN)	Advanced Pressurised Water Reactor
ARIMA	Auto-Regressive Integrated Moving Average
BIO-SNG	Synthetic Natural Gas
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CO <sub>2</sub>	Carbon Dioxide
EMF	Energy Modeling Forum
EMO	The Chamber of Electrical Engineers
EPWR (URN)	European Pressurised Water Reactor
ETSAP	Energy Technology Systems Analysis Program
EU	European Union
EÜAŞ	Electricity Generation Company
GAMS	The General Algebraic Modeling System
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GTCC	Gas Turbine Combined Cycle
GTMH	Gas Turbine Modular Helium
IEA	International Energy Agency
IGCC	Integrated gasification combined cycle
Magnox	Magnesium Alloy Graphite Moderated Gas Cooled Uranium Oxide
MARKAL	Market Allocation Model
MCFC	Molten Carbonate Fuel Cells
M pounds	Million Pounds
Mt	Megaton
MTA	General Directorate of Mineral Research and Exploration
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-operation and Development
PEMFC	Proton Exchange Membrane Fuel Cell
PF	Pulverized Fuel

PJ	Petajoule
PPP	Purchasing Power Parity
PV	Photovoltaic
PWR	Pressurised Water Reactor
RES	Reference Energy System
SOFC	Solid Oxide Fuel Cell
TL	Turkish Lira
TOE	Tons of Oil Equivalent
TUIK	Turkish Statistical Institute
UNFCCC	United Nations Framework Convention on Climate Change

## 1. INTRODUCTION

The need for energy is increasing each day with rapid population growth, globalization, industrialization and improved living standards because it is invaluable not only for the individuals but also for institutions and governments. Efficiently utilizing energy resources and managing the energy use provide a significant advantage to the nations. For this reason, governments must analyze and better understand their energy sector and be able to predict how the energy sector will evolve in the future.

On the other hand, energy production and consumption have great effects on the environment and public health. One of the most adverse effects of energy production and consumption is greenhouse gases, which account for about 80% of the total global emissions. It should be mentioned that electricity sector is the largest such emitting sector. This is one of the main reasons of focusing on the electricity generation sector and its impacts in this thesis.

The most important effect of greenhouse gas emissions is the global warming and climate change induced by the reduced reflection of sun's rays (as the name "greenhouse" implies). Even a few degrees increase in average global temperatures has the potential to create havoc through changes in droughts, extreme and frequent storms, increasing sea levels.

With the increasing demand for energy, policies for reliable, sufficient and economic energy supplies and CO<sub>2</sub> emission reductions become essential for all nations. With these issues in mind, the European Union (EU) proposed a package about climate change and energy on January 2007 that aimed to provide security of supply, competitiveness and environmental sustainability. One of the targets in this package (which is known as "20-20-20" package) was reducing EU Greenhouse Gas (GHG) emissions by 20%, compared to the year 1990 levels, by 2020 [1]. Furthermore, there is an important agreement, the Kyoto Protocol, that is linked to the United Nations Framework

Convention on Climate Change (UNFCCC), and which was adopted in December 1997 at Kyoto, Japan and came into force in February 2005. The Kyoto Protocol aims to reduce and mitigate global warming through major global reductions in GHG emissions. The Annex-I countries of the UNFCCC are obliged to reduce their GHG emissions by specific percentages within a specific timeframe. Turkey became a party to the Kyoto Protocol on August 2009. She is not listed in the Annex-B countries and not obliged to commit herself to a specific GHG emission target [2]. However, as a signatory party of the Kyoto Protocol, she has taken responsibility and intends to combat climate change. For instance, the number of wind projects in Turkey is fast increasing through new incentives about feed-in tariff for renewable energy resources. Also Turkey generates 20% of its electricity by utilizing renewable energy resources, and desires to increase this rate up to 30% by 2023. Based on this, some of the alternative scenarios, generated in this thesis study, focus on reducing overall CO<sub>2</sub> emissions 20% and 40% below the current CO<sub>2</sub> emissions level. These scenarios are helpful to policy makers and planners in establishing new energy policies.

Since Turkey is a fast developing country with growing economy and energy demands, while having few indigenous energy resources, she has to be very cautious about her future energy supply and demand, and security of energy.

There are large coal reserves in Turkey, accordingly a large part of the energy demand is supplied by coal, which is also heavily utilized to generate electricity. However, most of indigenous coal reserves are low energy and high pollutant content type; thus a large share of Turkey's coal consumption also depends on imports. Additionally, a large share of Turkey's energy demand is satisfied by natural gas which is imported from other countries. On the other hand, lately, incentives and support for renewable technologies have been increasing, leading to new investment and capacity in these technologies. In this regard, there are new regulations about these technologies to make them more competitive in the energy sector. Especially wind energy is encouraged since Turkey has a large potential in wind energy. In addition to this, Turkey aims to utilize more geothermal and solar energy resources in order to use its great potentials. Moreover, Turkey is planning to generate electricity from nuclear power plants to satisfy its growing energy demand.

This study features a “bottom-up”, long-term energy supply and demand balance modeling and analysis of the Turkish energy sector with special detailed analysis of the electricity generation sector. For this purpose, the “MARKAL” modeling environment (which is described and discussed in the second section and the MARKAL-TURKEY model developed in earlier studies [3-5] are deployed. The main contributions of the current study are, (i) the detailed and expanded remodeling of the electricity sector within the overall MARKAL-TURKEY model, (ii) extensive additional data collection and compilation regarding the electricity generation sector, (iii) extensive new scenario analysis focusing the electricity generation sector. CO<sub>2</sub> emission reduction policies, CCS technologies and nuclear power generation are key issues addressed in the scenario analysis conducted.

In the second chapter of this thesis study, a brief information about MARKAL modeling framework is provided. In the third chapter, a literature survey on energy modeling systems and the electricity sector is presented. Additionally, some global and local statistics on CO<sub>2</sub> emissions and the energy sector are presented. In the fourth chapter, a detailed MARKAL model of Turkish electricity sector is represented together with its underlying assumptions. In the fifth chapter, the developed scenarios (both base and alternative scenarios) are given and their results are analyzed. Finally, in the sixth chapter, all conclusions and implications of this study are summarized with closing remarks. In addition to this, recommendations for future research are presented.

## **2. THE MARKAL MODELLING FRAMEWORK FOR ENERGY SYSTEMS**

In this chapter, some explanatory information about the MARKAL energy modeling system is provided.

### **2.1. The MARKAL Energy Modeling System**

In the literature, there are many kinds of energy models according to the representation of commodities and technologies. The two main approaches of energy modeling systems are “Top-Down” and “Bottom-Up” models. Usually, the term “top” stands for aggregate and “Top-Down” models concentrate on entire market and economy. In contrast, “bottom” stands for disaggregate and “Bottom-Up” models feature disaggregated analysis that describes energy-using technologies and sectors in a detailed way [6]. These models are usually helpful to policy makers about determining least-cost mix of technologies and estimating the potential of a technology [7]. One of the bottom-up energy modeling environments is the MARKAL energy modeling system which is a technology explicit system.

MARKAL (an acronym for MARKet ALlocation) is a dynamic, linear optimization based energy modeling system which is suitable for deployment at national, regional, state, province, or community level. It is developed by the International Energy Agency’s (IEA) Energy Technology Systems Analysis Program (ETSAP). At present, the MARKAL modeling system is used in 37 countries to make long range supply, demand and investment plans in energy sectors, to estimate greenhouse gas emissions, to generate and evaluate strategic or tactical level scenarios and in general to help the top level decision making processes [8]. Developed MARKAL models are inputted, solved and reported through the “ANSWER” interface and through the mathematical modeling software GAMS during this process.

MARKAL is a bottom-up modeling energy system that balances supply and demand of energy sector. The MARKAL system enables and supports the users in the development of specific optimization models geared at supplying energy services at minimum cost, while meeting all energy demands, with an aim to optimize investments over the planning horizon. MARKAL models target to balance primary resources and secondary fuels, final energy, energy services at all levels [9].

It is possible to determine the key role and economic analysis of technologies by a MARKAL model. Impacts of taxes and subsidies on energy production and energy consumption can also be assessed [10]. As such, MARKAL models are very helpful to policy makers and planners especially in the planning of national and local energy systems and the long term development of the energy sector a country [11].

On the other hand, the MARKAL system and the model developed require an extensive database that contains qualitative, quantitative data, and technology-rich options. The qualitative data is regarding types of energy carriers, environmental emissions, and appropriate technologies over a specified time horizon. And quantitative data is the many associated technologic and economic parameters, assumptions for each technology, region and time period [12].

This modeling system contains energy carriers with primary supplies (e.g., mining, petroleum extraction, etc.), conversion and process technologies (e.g., power plants, refineries, etc.), and end-use demand for energy services (e.g., boilers, automobiles, residential space conditioning, etc.). There are some sub-sectors that represent specific demand for energy services such as agricultural sector, industrial sector, transportation sector and commercial sector. Accordingly, a typical MARKAL model includes energy demand, energy sources, sinks, technologies and commodities [9].

In the MARKAL system, each time period is generally 5-10 years. The user can define the number of periods and time horizon. Besides, there are diurnal divisions (usually 2 - day, night) and seasons (3 or 4 such as winter, summer, and intermediate) [9].

The MARKAL system focuses on the basic elements of Reference Energy System (RES) which is an interconnected network that depicts all energy producing, transforming, consuming processes, in other words it shows the summarization of various entities. In a typical MARKAL RES, commodities like energy carriers are shown by links (arcs) and technologies are shown by nodes.

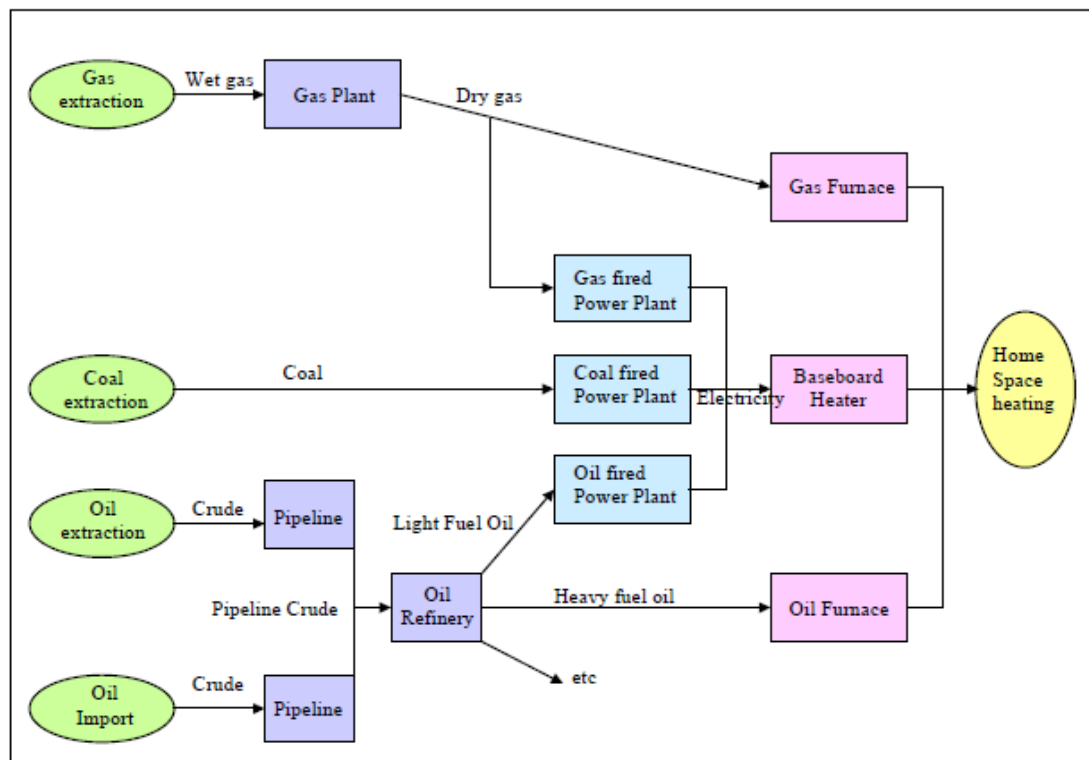


Figure 2.1. Partial view of a simple Reference Energy System [9].

## 2.2. Mathematical Formulation of the MARKAL Model

In this part, the simplified mathematical formulation of a MARKAL model is expressed by referring to Loulou et. al.'s "The documentation for the MARKAL family of model" [9]. There are three important parts in the underlying optimization problem:

- Objective function
- Decision variables
- Constraints

There are also some important indexes that are used by model variables and equations:

“ $r$ ” and “ $r'$ ” indicate region (omitted when a single region is modeled), “ $t$ ” is time period, “ $k$ ” is technology, “ $s$ ” is time-slice, “ $c$ ” is commodity (energy or material) and “ $l$ ” is price level (used only for multiple sources of the same commodity distinguished only by their unit cost).

### 2.2.1. Decision Variables

The decision variables, which are unknown and have a domain, are determined by the results of the optimization model. These are explained below:

*INV* ( $t,k$ ): New capacity addition for technology  $k$ , in period  $t$ . Units change according to the technologies. Electricity conversion technologies usually use GW ( $1GW=31.536 PJ/year$ ) as capacity unit. An investment is assumed to be available during its lifetime and new investments made in period  $t$  are assumed to be available at the beginning of that period.

*CAP* ( $t,k$ ): Installed capacity of technology  $k$ , in period  $t$ . Typical units are the same as for investments.

*ACT* ( $t,k,s$ ): Activity level of technology  $k$ , in period  $t$ , during time-slice  $s$ . The unit is PJ per year for all energy technologies. Since, there is an assumption that the activity level is equal to the available capacity for end-use technologies, *ACT* variables are not defined for these technologies.

*MINING* ( $t,c,l$ ): Quantity of commodity  $c$  (PJ per year) extracted at price level  $l$  in period  $t$ . The unit cost of extracting the commodity, which is provided by the user, is the coefficient in the objective function. These commodities are domestic production resources such as coal, petroleum, biomass and municipal solid waste.

$IMPORT (t,c,l)$ ,  $EXPORT (t,c,l)$ : Quantity of commodity  $c$ , (PJ per year) exogenously imported or exported in period  $t$ , at price level  $l$ . The exported and imported quantities are not automatically balanced by the model. The unit price of importing or exporting the commodity, which is to be provided by the user, is the coefficient of the import or export variable in the objective function.

$TRADE (t,c,s,imp)$  and  $TRADE (t,c,s,exp)$ : Quantity of commodity  $c$  (PJ per year) sold (exp) or purchased (imp) in period  $t$ , for time slice  $s$  (for electricity) .

$D (t,d)$ : Demand for end-use  $d$ , in period  $t$ .

$ENV (t,p)$ : Emission of pollutant  $p$  in period  $t$ .

### 2.2.2. The Objective Function

The objective of a MARKAL model is to minimize the total system cost, which is discounted over the planning horizon. Therefore, the discounted present value of annual costs is needed for the objective function.

$$NPV = \sum_{t=1}^{t=NPER} (1+d)^{NYRS \cdot (t-1)} \cdot ANNCOST(t) \cdot \left( \frac{1+(1+d)^{-1} + (1+d)^{-2}}{+\dots+(1+d)^{1-NYRS}} \right) \quad (2.1)$$

where  $NPV$  is the net present value of the total costs for all regions,  $d$  is the general annual discount rate,  $NPER$  is the number of periods in the planning horizon,  $NYRS$  is the number of years in each period  $t$ ,  $ANNCOST (t)$  is the annual cost for period  $t$  whose formulation is expressed below :

$$\begin{aligned}
ANNCOST(t) = & \sum_k \left\{ \begin{aligned} & Annualized_{Inv\text{cost}(t,k)} * INV(r,t,k) \\ & + Fixom(t,k) * CAP(t,k) \\ & + Varom(t,k) * \sum_s ACT(t,k,s) \end{aligned} \right\} \\
& + \sum_c \left[ Deliv\text{cost}(t,k,c) * Input(t,k,c) * \sum_s ACT(t,k,c) \right] \\
& + \sum_{c,s} \left\{ \begin{aligned} & Mining\text{cost}(t,c,l) * Mining(t,c,t) \\ & + Tradecost(t,c) * TRADE \left( t,c,s, \frac{i}{e} \right) \\ & + Import\text{price}(t,c,l) * Import(t,c,l) \\ & - Export\text{price}(t,c,l) * Export(t,c,l) \end{aligned} \right\} \\
& + \sum_c \{ Tax(t,p) * ENV(t,p) \} \\
& + \sum_d \{ DemandLoss(t,d) \} \tag{2.2}
\end{aligned}$$

where  $Fixom(k,t)$  and  $Varom(k,t)$  are the unit fixed and variable operational maintenance costs of technology  $k$  in period  $t$ ;  $Deliv\text{cost}(k,t,c)$  is delivery cost per unit of commodity  $c$  to technology  $k$  in period  $t$ ;  $Input(t,k,c)$  is the amount of commodity  $c$  required to operate one unit of technology  $k$ , in period  $t$ ;  $Mining\text{cost}(t,c,l)$  is the unit cost of mining commodity  $c$ , at price level  $l$ , in period  $t$ ;  $Tradecost(t,c)$  is the unit transport and transaction cost for commodity  $c$  exported or imported in period  $t$ ;  $Import\text{price}(t,c,l)$  is the import price of commodity  $c$  in period  $t$ ;  $Export\text{price}(t,c,l)$  is the export price of commodity  $c$  in period  $t$ ;  $Tax(t,p)$  is the tax on unit of emission  $p$  in period  $t$ ;  $DemandLoss(t,d)$  is the representation of welfare loss (in non-reference scenarios) incurred by consumers when a service demand  $d$  in period  $t$  is less than its value in the reference case.

$$ANNUALIZED\_INVCOST = INVCOST / \sum_{j=1}^{LIFE} (1+h)^{-j} \tag{2.3}$$

where  $INVCOST$  is the lumpsum unit investment cost of a technology,  $ANNUALIZED\_INVCOST$  is the annualized equivalent of  $INVCOST$ ,  $LIFE$  is the economic lifetime of a technology (the number of years that a technology is available from the year of initial installations),  $h$  is the technology-specific discount rate (also called hurdle rate).

The total annual cost  $ANNCOST(t)$  is the sum over all technologies  $k$ , all demand segments  $d$ , all pollutants  $p$ , and all input fuels  $f$ , of the various costs like annualized investments, annual operating costs such as fixed and variable costs, fuel delivery costs, extracted and imported energy carriers' cost, minus revenue from exported energy carriers, plus taxes on emissions, plus cost of demand losses.

### 2.2.3. Constraints

2.2.3.1. Satisfaction of Demands. These constraints require that for each time period  $t$ , demand  $d$ , the total activity of end-use technologies servicing that demand must be at least equal to the specified demand.

$$\sum_{\text{all end-use technologies } k} CAP(t,k) \geq D(t,d)$$

such that,  $k$  supplies service  $d$

(2.4)

2.2.3.2. Capacity Transfer.

$$CAP(t,k) = \sum_t \sum_{\text{all periods } t'} INV(t',k) + RESID(t,k)$$

such that  $t-t' \leq LIFE(k)$

(2.5)

where  $RESID(t,k)$  is the capacity of technology  $k$  due to investments made prior to the initial model period and still exists at time  $t$ . Capacity transfer constraints ensure that for each technology  $k$ , period  $t$ , the available capacity in period  $t$  is equal to the sum of investments made by the model in the past and current periods. When computing the available capacity in some time period, the model takes into account the capacity resulting from all investments up to that period, some of which may have been made prior to the initial period but are still in operating condition (embodied by the residual capacity of the

technology), and others that have been decided by the model at, or after, the initial period, but prior to the period in question.

2.2.3.3. Use of Capacity. The activity level of the technology may not exceed its available capacity, as specified by a user defined availability factor for each technology  $k$ , period  $t$ , and time slice  $s$ .

$$ACT(t,k,s) \leq AF(t,k,s) \cdot CAPUNIT \cdot CAP(t,k) \quad (2.6)$$

where  $AF(t,k,s)$  is the fraction of time that the capacity is available to operate for each technology  $k$ , period  $t$  and time slice  $s$ ;  $CAPUNIT$  factor allows for capacity units to be converted into electricity production units.

Since an activity variable for end-use technologies is not defined, this constraint is not expressed for end-use technologies.

2.2.3.4. Energy Balance. According to this group of constraints, the disposition of each commodity  $c$  may not exceed its supply for time period  $t$  (and time-slice  $s$  in the case of electricity and low-temperature heat).

$$\left[ \begin{array}{l} \sum_k Output(t,k,c) \cdot ACT(t,k,s) + \sum_l MINING(t,c,l) \\ + \sum_l FR(s) \cdot IMP(t,c,l) + XCVT(c,i) \cdot TRADE(t,c,s,i) \end{array} \right] \geq \left[ \begin{array}{l} XCVT(c,o) \cdot TRADE(t,c,s,e) + \sum_l FR(s) \cdot EXP(t,c,l) \\ + \sum_k Input(t,k,c) \cdot ACT(t,k,c,s) \end{array} \right] \quad (2.7)$$

where,  $Input(t,k,c)$  is the amount of commodity  $c$  required to operate one unit of technology  $k$ , for period  $t$ ,  $Output(t,k,c)$  is the amount of commodity  $c$  produced per unit of technology  $k$ , for period  $t$ ,  $FR(s)$  is the fraction of the year covered by time-slice  $s$ ,  $XCVT(c,i)$  and  $XCVT(c,o)$  are transaction or transport costs of importing or exporting one unit of commodity  $c$ .

2.2.3.5. Emission Constraint or Emission Tax. According to this group of constraints, for each time period  $t$ , the total emission of pollutant  $p$  should not be greater than a user-selected upper bound, if such a bound is provided. It is optional to use these constraints.

$$ENV(t,p) = \sum_{\text{all technologies } k} \left[ \begin{array}{l} Eminv(t,p,k) * INV(t,k) \\ + Emcap(t,k,p) * CAP(t,k) \\ + Emact(t,k,p) * \sum_s ACT(t,k,s) \end{array} \right]$$

$$ENV(t,p) \leq ENV\_Limit(t,p) \quad (2.8)$$

where  $Eminv$ ,  $Emcap$ ,  $Emact$  are emission coefficients for pollutant  $p$  linked respectively to the construction, the capacity, and the operation of a technology;  $ENV\_LIMIT(t,p)$  is the upper limit set by the user on the total emission of pollutant  $p$  in period  $t$ .

Moreover, it possible to specify an emission tax  $Etax(t,p)$  rather than an emission limit. When an emission tax is applied, the quantity  $ENV(t,p) * Etax(t,p)$  is added to the  $ANNCOST$  expression to penalize emissions at a constant rate.

2.2.3.6. Electricity Baseload Constraints. Electricity generating technologies that are labeled as baseload must produce the same amount of electricity at night as in the day in any period  $t$ . However, their production may change from season to season. This group of constraints provide that only a maximum percentage of the total night-time demand for electricity is met by such plants.

$$\sum_{\substack{\text{all technologies } k \text{ consuming} \\ \text{electricity } c \text{ at night of}}} \{Input(t,c,k) * Baseload(t,c) * ACT(t,k,'N')\} \geq$$

$$\sum_{\substack{\text{all baseload technologies } k \\ \text{producing electricity } c \text{ at night of}}} \{Output(t,k,c) * ACT(t,k,'N')\} \quad (2.9)$$

where *Baseload* ( $t,c$ ) is the maximum share of the night demand for electricity  $c$  in period  $t$ .

Nuclear power plants and solid fuel plants are included in the baseload set and those technologies' operation must not fluctuate from day to night.

### 2.2.3.7. Electricity and Heat Energy Peak Reserve Constraints.

According to this constraint set, there must be sufficient installed capacity to meet the required capacity in the season with the largest electricity or (heat) commodity  $c$  (energy or material) demanded by a safety factor  $E$  (called peak reserve factor), for each time period  $t$ .

$$\begin{aligned}
 & \sum_{\text{all technologies } k} CAPUNIT * Peak(r,t,k,c) * FR(s) * CAP(r,t,k) + XCVT(c,i) \\
 & * TRADE(r,t,c,s,i) + FR(s) * IMPORT(r,t,c) \\
 & \geq [1 + ERESERVE(r,t,c)] * [ \sum_{\text{all technologies } k} INPUT(r,t,k,c) * FR(s) * ACT(r,t,k,s) \\
 & + XCVT(c,o) * TRADE(r,t,c,s,e) + FR(s) * EXPORT(r,t,c) ] \quad (2.10)
 \end{aligned}$$

where *ERESERVE* ( $r,t,c$ ) is the region specific reserve coefficient and  $r$  is region.

*ERESERVE* is chosen to ensure against possible electricity shortfalls due to uncertainties regarding electricity supply that may decrease capacity in an unpredictable way (for instance, unexpected down time of equipment, peak demand, and uncertain hydro, solar, or wind power availability). However, it should be mentioned that the MARKAL-Turkey is a single-region model.

*Peak*( $r,t,k,c$ ) specifies the fraction of technology  $k$ 's capacity in a region  $r$  for a period  $t$  and commodity  $c$  (electricity or heat only) that is allowed to contribute to the peak load. The electricity peaking constraint assures that there is enough capacity in place to meet the electricity demand during the day of the season with the highest demand.

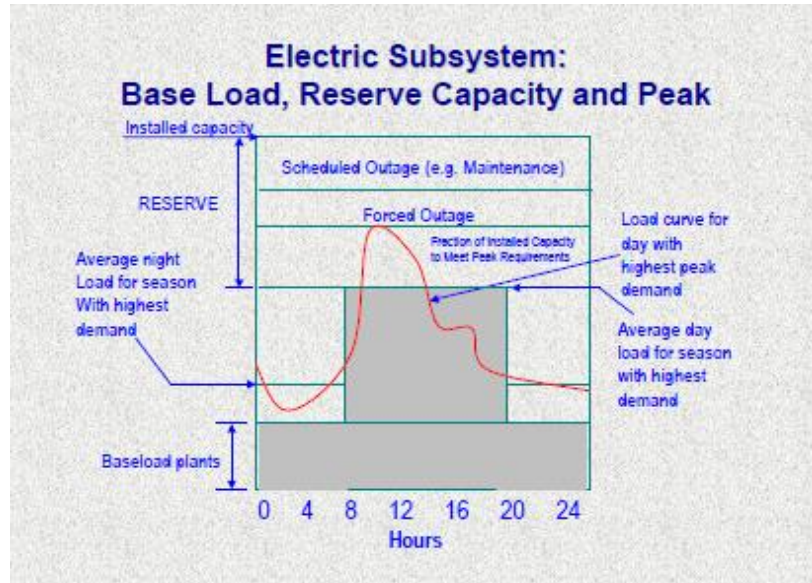


Figure 2.2. Baseload, reserve capacity and peak [9].

Moreover, it is possible to add user-defined constraints to the model.

### 2.3. The MARKAL-Turkey Model

The MARKAL regional and national models generated by the MARKAL system are some of the most widely used energy models. Policy makers and planners use the MARKAL modeling system to prepare a detailed and comprehensive model and integrated scenarios that contribute to their analyses. They benefit from the resulting modeling study to recognize the interaction between technologies and fuels and achieve environmental and energy goals [13]. There also exist various MARKAL models for TURKEY that permit compilation of long term energy scenarios and environmental analyses [14].

The MARKAL-Turkey model, which is used in this study, is one such detailed model of the Turkish energy sector that aims to balance supply and demand of national energy needs at minimum cost. It is developed at Boğaziçi University, associated with a project and as the subject of a series of graduate thesis. For instance, Cirit [4] has studied on the developed MARKAL-Turkey model sector in his thesis study and evaluated the CO<sub>2</sub> emissions while concentrating on the transportation. Alemdar [5] has proposed a thesis study on the MARKAL-Turkey model with special emphasis to industrial sector. Apart from them, there is also a study, carried out by Karali [3], about energy modeling

systems. She has proposed a new bottom-up, large scale energy modeling framework which is a straight forward, flexible, general purpose and optimization modeling. She has also conducted a scenario analysis with the aim of analyzing the effects of alternative approaches on energy dynamics.

In this thesis study, the electricity generation sector of the MARKAL-Turkey model is revised and expanded. For instance, many electricity generation technologies are subdivided and regrouped according to the technological characteristics, and of course, their expanded data requirements are satisfied through extensive additional data compilation.

Figure 2.3, shows the simplified Reference Energy system (RES) of the MARKAL Turkey model. As it is showed in this figure, the MARKAL – Turkey model includes six main parts: Primary Energy Resources, Conversion Technologies, Energy Carriers, Production Technologies, End-Use Technologies and Demand Sectors. Primary energy sources, which are the starting point of the energy system, are used in conversion technologies such as refineries and power plants, like coal fired combined cycle power plants. These conversion technologies produce energy carriers like electricity and heat. The energy carriers are then consumed in production and end-use technologies such as, space heating, transport vehicles, cooking equipment. These end-use technologies are also called demand technologies and they produce useful energy to satisfy energy demand of demand sectors. Agricultural, industrial, residential, services and transport sectors are the main end-use demand categories in the MARKAL Turkey model.

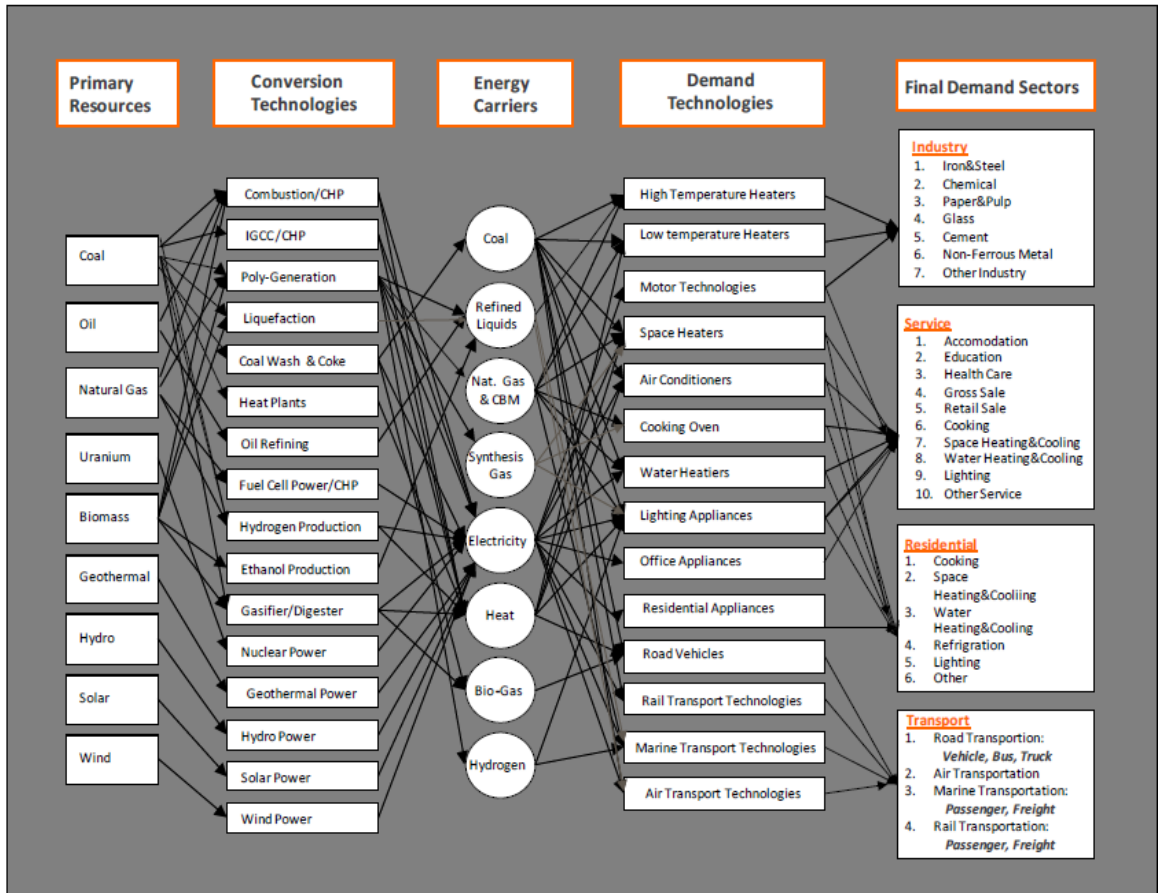


Figure 2.3. A simplified representation of MARKAL-Turkey model components [5].

### **3. LITERATURE SURVEY**

This chapter contains a literature survey and important statistics about CO<sub>2</sub> emissions and the energy sector, while giving special emphasis to the electricity sector for both the World in general and Turkey in particular.

#### **3.1. Research in Energy Modeling Systems and Electricity Generation**

Suganthi and Samuel [15] study and present various models for energy demand forecasting. The existing state of energy resources and managing these resources efficiently provide a competitive advantage to the nations. In order to manage energy resource effectively and supply the energy needs, an integrated energy demand management approach is indispensable. Therefore, this study focuses on energy demand forecasting models, featuring the review of various energy demand forecasting models. These models are categorized into 12 classes: Time series models, regression models, econometric models, decomposition models, cointegration models, Auto-Regressive Integrated Moving Average (ARIMA) models, artificial systems, grey prediction models, input-output models, fuzzy logic-genetic algorithm models, integrated models and bottom-up models. This review study demonstrates that macro-economic energy modeling has great importance for every nation to accurately predict energy demand.

There are various studies about energy models. Smekens and Morales [16] uses a MARKAL modeling system to generate scenarios while taking into account the Energy Modeling Forum (EMF) assumptions. Their MARKAL model covers the 1990-2100 period at 10 years interval and features more than 850 technologies. Various Western European countries are stated as the study region of the model. The scenarios consist of carbon emission reduction targets. There are 8 scenarios which differ from each other according to carbon emission reduction targets and carbon taxes. The results indicate that the carbon emission targets can be achieved by changing the future technology mix and giving more weight to renewable energy technologies and CCS technologies.

Kumbaroğlu *et al.* [17] proposes a model for the diffusion prospects of new renewable energy technologies. They focus on the integration of learning curves for renewable energy technologies into a dynamic programming model. The proposed model is applied to the real data for the Turkish electricity supply industry. Furthermore, they generate an empirical analysis by developing different scenarios. Results of this study show the importance of technological learning and policies that support renewable power generation.

Schulz *et al.* [18] propose a cost-optimization model for the Swiss energy sector by using a SWISS-MARKAL model. The desire of the Swiss State to encourage usage of renewable energy resources, especially biomass-based energy carriers (which are candidates for taking the place of fossil fuels) is specially reflected in this model. This study puts emphasis on wood-based energy technologies in Switzerland. It is conducted to assess the development and effects of wood methanation plants which produce synthetic natural gas (bio-SNG). Scenario analyses are related to oil price increases and subsidies to the methanation plants. The results of the scenarios show that bio-SNG is of great importance for the transport sector rather than the residential sector.

Aboumahboub *et al.* [19] formulate a multi-regional electricity system investment and production optimization model, which is based on linear programming by using the General Algebraic Modeling System (GAMS). This electricity system optimization model represents interconnected electricity supply system, while considering technical restrictions of power plants on, technology level, temporal fluctuations and geographical dependencies of renewable energy sources, and exogenously imposed boundary conditions. The model, which is a representation of the German electricity system, includes 50 regions and these regions are determined according to the geographic distribution of electricity demand and renewable supply, and also political borders. The factors that affect CO<sub>2</sub> emissions of the electricity generation, such as fuel prices and renewable energy consumption, etc. are also analyzed. The results of sensitivity analyses show that the share of wind and solar energy is increasing to reduce CO<sub>2</sub> emissions. Also it is claimed that wind energy is a powerful energy resource to achieve emission reduction targets. One of the conclusions of this study is that the structure of electricity system and fuel price relationships affect the CO<sub>2</sub> emissions abatement.

Mondal *et al.* [20] use the MARKAL Bangladesh model to evaluate the long-term impacts of CO<sub>2</sub> emission reduction and carbon tax applications in Bangladesh. While more than half of the population is deprived of electricity at present, the state aims to satisfy the electricity demand of the whole country by 2020. The base, 10% emission reduction, 20% emission reduction, carbon tax of 1500 taka/ton and 2500 taka/ton scenarios are investigated. The planning horizon of these scenarios is from 2005 to 2035. The results show that total electricity generation capacity should be increased from 5.56 Giga-Watt (GW) in 2005 to 53.82 GW in 2035. The primary fuel consumed to generate electricity is coal which is the major source of CO<sub>2</sub> emissions. Besides, emission reduction restrictions have great influence on the preference of energy resource. The model selects clean and renewable technologies. Especially, the solar PV (photovoltaic) technology is the most attractive one, since its costs are assumed to be relatively cheaper in Bangladesh than those in the developed countries.

Broek *et al.* [21] conduct a study about the usage and role of Carbon Capture and Storage (CCS) technologies. The MARKAL model for Netherland is used to generate scenarios about energy planning and strategies. By generating CO<sub>2</sub> emission reduction scenarios, the role of CCS technologies in the electricity sector is analyzed and fuel types are investigated. Especially the changes in the electricity generation sector are tracked. The planning horizon is from 2000 to 2050, at 5-year time intervals and the costs are discounted back to the year 2000 with 5% discount rate. In the scenarios 15% and 50% emission reduction targets are investigated. This paper develops two strategies. The first one is DirectAction, in which 15% of CO<sub>2</sub> emissions are reduced from 2010 onwards. The second one is PostponedAction in which 50% of CO<sub>2</sub> emissions are reduced from 2020 onwards. According to the results of this study, installation of CCS technologies is reasonable if cogeneration and onshore wind energy technologies are limited and also nuclear power generation is not allowed. In the direct action strategy, the marginal cost of CO<sub>2</sub> is 50 €/t in 2015 and decreases to 25€/t in 2050. But, in the postponement strategy, it is 30 €/t in 2020. However, cumulative CO<sub>2</sub> emissions over the planning horizon are higher in the postponement strategy than in the direct strategy. As a result, the installation of new coal-fired plants with CCS should be postponed to 2020, since this way is more cost effective than the others.

Tunç *et al.* [22] evaluate Turkey's energy resources, installed electric power capacity, electric energy production and consumption rate. In this study, which covers the 1990 to 2001 period, the installed electricity generation capacity and the production and consumption of petroleum, dry gas and coal in Turkey are given. Also, these are compared with France, Germany and Switzerland. It is worth mentioning that Germany is the largest electricity market in Europe with 544.8 Billion Kilowatt Hours (BkWh) generated electricity in 2001. A linear mathematical optimization model that anticipates the distribution of future electrical supply investments while minimizing total energy production cost in Turkey is proposed. The proposed model has only four variables ( $X_1$ : fossil oil, diesel and coal,  $X_2$ : natural gas,  $X_3$ : nuclear and  $X_4$ : hydro and renewable energy). According to the results of the model, the total cost with nuclear power energy generation is 6,888,000,000\$ to produce 222,000 Giga-Watt Hours (GWh) electricity for the year 2010. However, if nuclear power energy is not allowed, the total cost increases to 7,006,300,000\$ at the same year.

### **3.2 Some Key Global and Local Energy Statistics**

#### **3.2.1. Energy Outlook in the World**

Energy demand and consumption are continuously increasing as a direct result of high population growth, globalization, industrialization and economic development. Therefore, energy problem comes into prominence and the strategic importance of energy sector for national policies becomes significant.

Energy can be found in many forms in nature; it is then transformed into preferred forms according to consumers' needs. Primary energy carriers are found in natural resources and are not exposed to any transformations or conversions [23]. However, a secondary energy form is obtained from primary energy sources by transformation or conversion processes [24].

Consumers need useful energy which is an energy form that final consumers use it to satisfy their requirements. The demand for useful energy is categorized into different sectors such as industrial, transportation, residential, commercial, and agricultural. For

instance, households need energy to satisfy certain personal needs; industries need energy for production; transportation sector needs energy for air, water, rail and road transport; residential and commercial sectors need energy for heating, electrical appliances including lighting, etc. The amount of useful energy consumed by sectors varies according to the degree of countries' economic development and industrialization [24].

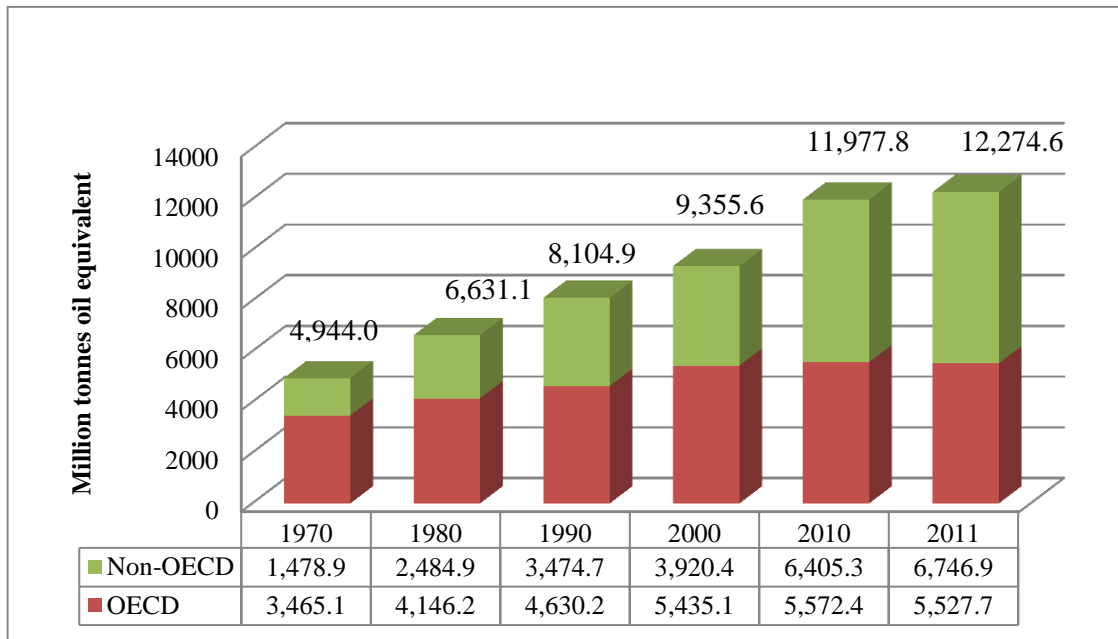


Figure 3.1. World primary energy consumption [25].

In this section, some key statistics about the energy profile in the World and Turkey are presented. When energy consumption is examined, it is seen that, until the 2000s, the primary energy consumption in Organization for Economic Co-operation and Development (OECD) countries was greater than the non-OECD countries. However, after 2000s, this case is reversed. Since economic growth and expanding population are directly related to the energy demand, the influences of global recession of 2008-2009 on energy demand can be easily observed. Today, the recovery from the global recession, still continues. The OECD member countries generally have more advanced economies and their recovery is slower than past recessions. On the other hand, the energy demand growth of the non-OECD countries has remained high during global recession. Besides, it's worth mentioning that China and India (that are the major non-OECD countries in Asia Pacific) have highly increasing energy use with their economic growth. [26].

Table 3.1. World primary energy consumptions by regions (Million Tons of Oil Equivalent (Mtoe)) [25].

Regions	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2011 share of total
Turkey	73	78	83	86	96	103	103	103	109	119	1.0%
<b>Total Europe &amp; Eurasia</b>	<b>2,849</b>	<b>2,913</b>	<b>2,958</b>	<b>2,969</b>	<b>3,009</b>	<b>3,003</b>	<b>3,007</b>	<b>2,831</b>	<b>2,939</b>	<b>2,923</b>	<b>23.8%</b>
<b>Total Middle East</b>	<b>465</b>	<b>486</b>	<b>523</b>	<b>562</b>	<b>587</b>	<b>612</b>	<b>652</b>	<b>671</b>	<b>716</b>	<b>748</b>	<b>6.1%</b>
<b>Total Africa</b>	<b>288</b>	<b>302</b>	<b>321</b>	<b>327</b>	<b>331</b>	<b>350</b>	<b>368</b>	<b>366</b>	<b>382</b>	<b>385</b>	<b>3.1%</b>
China	1,106	1,277	1,512	1,659	1,832	1,951	2,042	2,210	2,403	2,613	21.3%
India	309	317	346	364	382	416	446	488	521	559	4.6%
<b>Total Asia Pacific</b>	<b>2,800</b>	<b>3,014</b>	<b>3,328</b>	<b>3,535</b>	<b>3,755</b>	<b>3,947</b>	<b>4,060</b>	<b>4,254</b>	<b>4,558</b>	<b>4,803</b>	<b>39.1%</b>
<b>Total World</b>	<b>9,614</b>	<b>9,950</b>	<b>10,450</b>	<b>10,754</b>	<b>11,048</b>	<b>11,348</b>	<b>11,493</b>	<b>11,391</b>	<b>11,978</b>	<b>12,275</b>	<b>100.0%</b>
OECD	5,448	5,507	5,622	5,669	5,674	5,718	5,661	5,389	5,572	5,528	45.0%
Non-OECD	4,165	4,443	4,828	5,086	5,375	5,629	5,832	6,003	6,405	6,747	55.0%

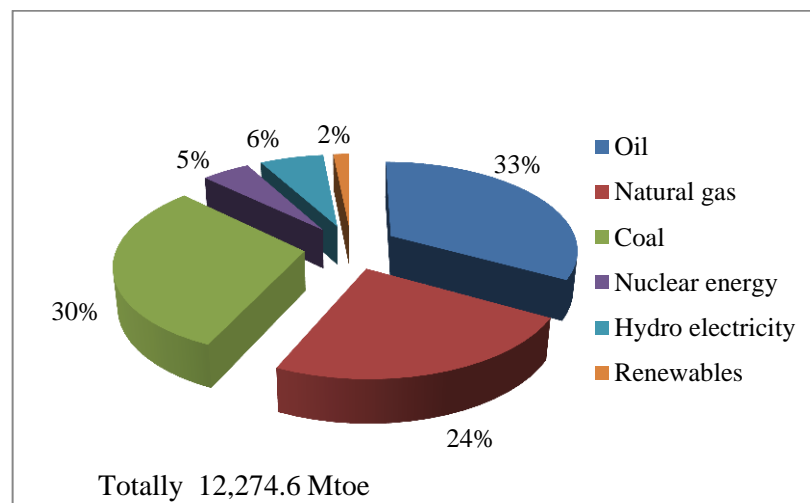


Figure 3.2. World primary energy consumption by fuel types in 2011 [25].

Figure 3.2 shows the fuel share of total primary energy consumption. As it is shown in the figure, as of 2011, oil is the leading fuel with 33% and it is followed by coal which has 30% share.

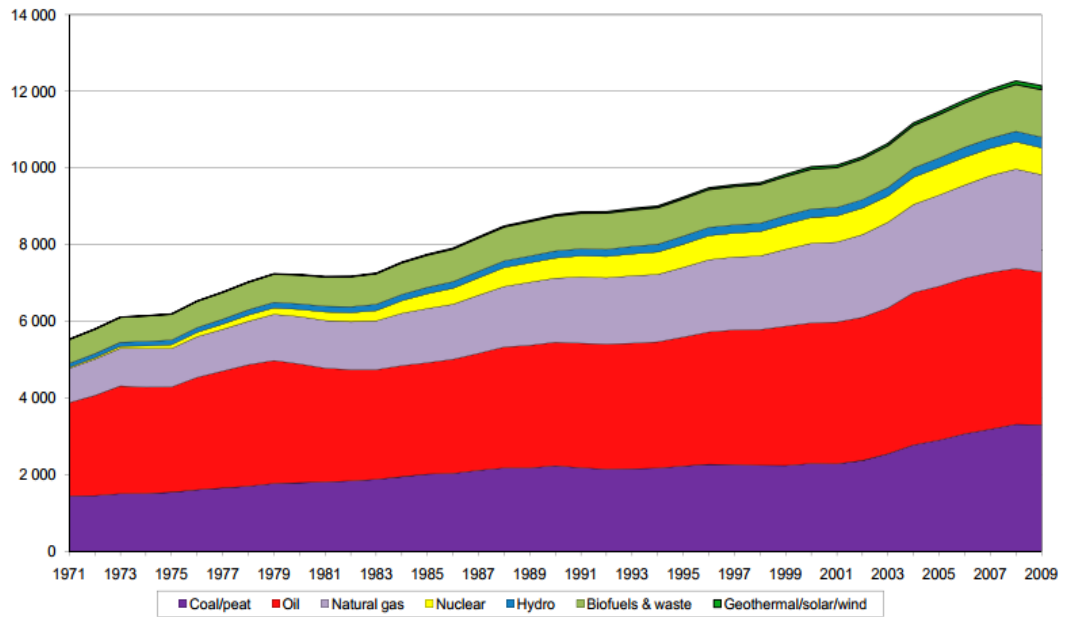


Figure 3.3. Total primary energy supply in the World [27].

Total global primary energy supply from 1971 to 2009 can be seen from Figure 3.3. As it can be inferred from Figure 3.1 and 3.3, the total supply is increasing as the primary energy consumption increases.

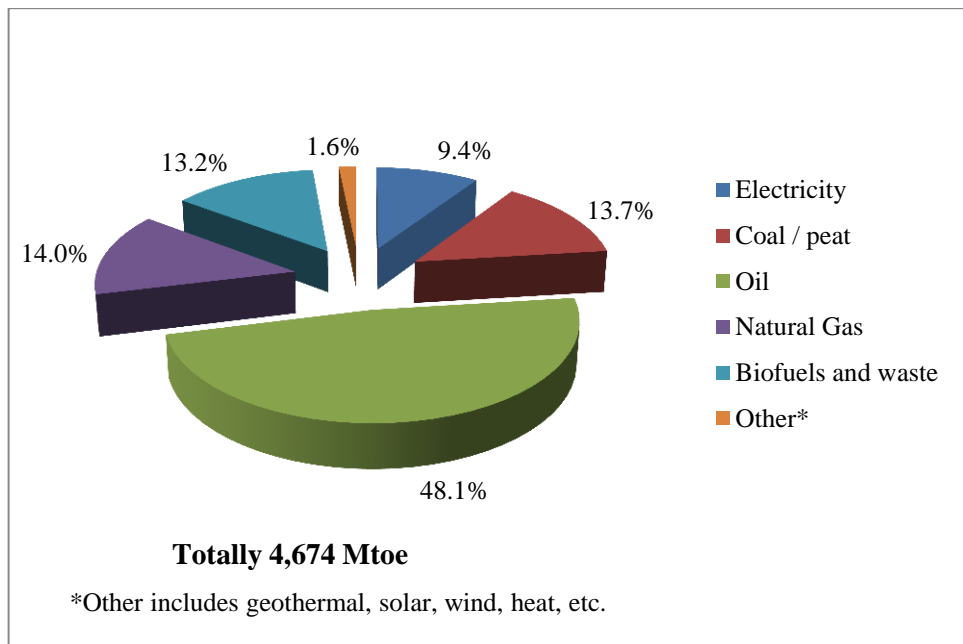


Figure 3.4. Fuel shares of total final energy consumption in the World in 1973 [27].

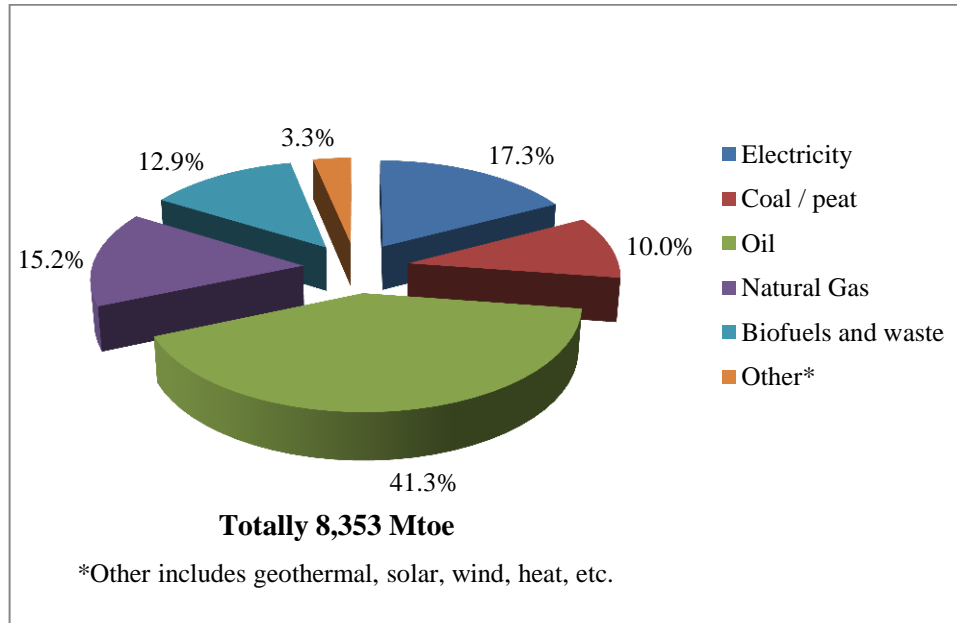


Figure 3.5. Fuel shares of total final energy consumption in the World in 2009 [27].

Figure 3.4 and 3.5 show the global final energy consumption profile. When final energy consumption in 1973 is compared with 2009, it is seen that total energy consumption has increased by 78%. Besides, oil has the largest share in the final energy consumption from 1973 to 2009.

Table 3.2. A comparison of socio-economic, energy and carbon data for OECD countries and the World in 2008 [28].

INDICATORS		OECD COUNTRIES	WORLD
SOCIO-ECONOMIC	Gross Domestic Product (GDP) (billion 1000 US\$)	61,008	80,964
	Population (million people)	1,190	6,688
	Per Capita GDP (thousand 1000 US\$/person)	51.26	12.10
ENERGY	Total Primary Energy Supply (MTOE)	5,422	12,267
	Total Electricity Consumption (billion kWh)	10,097	18,603
	Per Capita Primary Energy Supply (TOE/person)	4.56	1.83
	Per Capita Electricity Consumption (kWh/person)	8,486	2,782
	Energy Intensity of Economy (TOE/thousand 1000 US\$)	0.09	0.15
CARBON	Total CO <sub>2</sub> Emissions (Million Tons of CO <sub>2</sub> (Mt CO <sub>2</sub> ))	12,630	29,381
	Per Capita CO <sub>2</sub> Emissions (ton of CO <sub>2</sub> /person)	10.61	4.39
	Carbon Intensity of Economy (ton of CO <sub>2</sub> /thousand 1000 US\$)	0.21	0.37
	Carbon Intensity of Energy Supply (ton of CO <sub>2</sub> /TOE)	2.33	2.40

### 3.2.2. Energy Outlook in Turkey

This section gives information about Turkey's energy usage profile. As it is displayed in Table 3.3, the total primary energy supply has increased by 85.9% from 1990 to 2008 and GDP has increased by 170.8%.

One of the indicators of energy efficiency is energy intensity which is energy use per GDP. As can be inferred from Table 3.3, Turkey's energy intensity of economy has decreased by about 15%.

Table 3.3. A Comparison of Turkey's socio-economic, energy and carbon indicators for 1990-2008 [28].

INDICATORS		1990	2008	1990-2008 (% Change)
SOCIO- ECONOMIC	GDP (PPP) (billion 1000 US\$)	613.8	1662.32	170.82
	Population (million people)	56.20	71.08	26.48
	Per Capita GDP (PPP) (1000 US\$/person)	10,932.00	23,386	113.92
ENERGY	Total Primary Energy Supply (MTOE)	53	98.50	85.85
	Total Electricity Generation (billion kWh)	57.50	198.40	245.04
	Per Capita Primary Energy Supply (TOE/person)	0.94	1.39	47.87
	Per Capita Electricity Generation (kWh/person)	1,020	2,791	173.63
	Per Capita Electricity Consumption (kWh/person)	1,024	2,400	134.38
	Energy Intensity of Economy (TOE/thousand 1000 US\$-PPP)	0.09	0.06	-29.41
CARBON	Total Greenhouse Gas Emissions(Mton CO <sub>2</sub> e)	187.03	366.50	95.96
	Total CO <sub>2</sub> Emissions(Mton CO <sub>2</sub> )	126.70	270.86	113.78
	Greenhouse Gas Emissions from Electricity Production (Mton CO <sub>2</sub> e)	30.44	101.79	334.40
	Total Sinks (Mton CO <sub>2</sub> e)	44.87	80.58	79.59
	Per Capita Greehouse Gas Emissions (ton CO <sub>2</sub> e/person)	3.33	5.16	54.94
	Carbon Intensity of Economy (ton CO <sub>2</sub> e/1000 US\$-PPP)	0.31	0.22	-27.87
	Carbon Intensity of Energy Supply (ton CO <sub>2</sub> e/TOE)	2.39	2.75	15.06

Table 3.4. Primary Energy Resource Production [29].

Years	Hard Coal (kt)	Lignite (kt)	Asphaltite (kt)	Oil (kt)	Natural Gas (10 <sup>6</sup> M <sup>3</sup> )	Hydro And Geothermal Electricity (Gwh)	Geothermal Heat (KToe)	Wind (Gwh)	Solar (KToe)	Wood (kt)	Animal And Plant Waste(kt)	Biofuel (kt)	Total (KToe)
2000	2,392	60,854	22	2,749	639	30,955	648	21	262	16,938	5,981		26,047
2001	2,494	59,572	31	2,551	312	24,100	687	33	287	16,263	5,790		24,576
2002	2,319	51,660	5	2,442	378	33,789	730	62	318	15,614	5,609		24,282
2003	2,059	46,168	336	2,375	561	35,419	784	48	350	14,991	5,439		23,783
2004	1,946	43,709	722	2,276	708	46,177	811	61	375	14,393	5,278		24,332
2005	2,170	57,708	888	2,281	897	39,655	926	58	385	13,819	5,127		24,549
2006	2,319	61,484	452	2,176	907	44,338	898	127	403	13,411	4,984	2	26,580
2007	2,462	72,121	782	2,134	893	36,007	914	355	420	12,932	4,850	14	27,455
2008	2,601	76,171	630	2,160	1,017	33,432	1,011	847	420	12,264	4,883	20	29,209
2009	2,863	75,577	1,058	2,237	685	36,395	1,250	1,495	429	11,766	4,862	10	30,328

Table 3.5. Primary Energy Resource Consumption [29].

Years	Hard Coal (kt)	Lignite (kt)	Asphaltite (kt)	Oil (kt)	Natural Gas (10 <sup>6</sup> M <sup>3</sup> )	Hydro And Geothermal Electricity (Gwh)	Geothermal Heat (KToe)	Wind (Gwh)	Solar (KToe)	Wood (kt)	Animal And Plant Waste (kt)	Electricity Import (GWh)	Electricity Export (GWh)	Biofuel (kt)	Total (KToe)
2000	15,525	64,384	22	31,072	15,086	30,955	648	33	262	16,938	5,981	3,791	-437		80,500
2001	11,176	61,010	31	29,661	16,339	24,100	687	62	287	16,263	5,790	4,579	-433		75,402
2002	13,830	52,039	5	29,776	17,694	33,789	730	48	318	15,614	5,609	3,588	-435		78,331
2003	17,535	46,051	336	30,669	21,374	35,419	784	61	350	14,991	5,439	1,158	-588		83,826
2004	18,904	44,823	722	31,729	22,446	46,177	811	58	375	14,393	5,278	464	-1,144		87,818
2005	19,421	56,571	738	31,062	27,171	39,655	926	59	385	13,819	5,127	636	-1,798		91,074
2006	22,798	60,184	602	31,395	31,187	44,338	898	127	403	13,411	4,984	573	-2,236	2	99,642
2007	25,388	72,317	632	32,143	36,682	36,007	914	355	420	12,932	4,850	864	-2,422	12	107,627
2008	22,720	75,264	630	30,877	36,928	33,432	1,011	847	420	12,264	4,883	789	-1,122	20	106,421
2009	23,698	75,641	1,010	29,845	35,800	36,395	1,250	1,495	429	11,766	4,862	812	-1,546	10	106,138

Primary energy resource consumption depends on primary energy resource production. For this reason, Tables 3.4 and 3.5 are very similar to each other except for the columns of hard coal, oil and natural gas. Since a large share of hard coal, oil and natural gas is imported, there is a gap between the production and consumption amount of these energy resources in Turkey.

Table 3.4 depicts that the production of geothermal, wind and solar energy in Turkey is increasing each year. Moreover, there is a gradual increase in total primary energy production from 2000 to 2009. Also, there is an increase in the level of total primary energy supply from 1971 to 2009 as it can be seen from Figure 3.6.

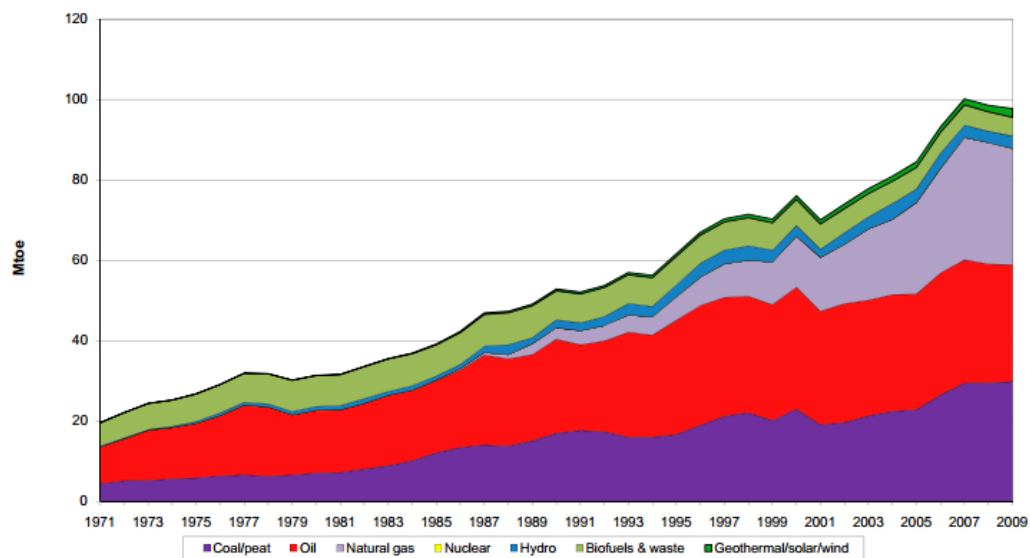


Figure 3.6. Total primary energy supply in Turkey [30].

It should be mentioned that the energy consumption has doubled from the year 1990 (52,646 TOE) to the year 2009 (106,138 TOE) [29]. As an indicator of development in a country, energy consumption per capita increases, which explains the increase in this energy consumption from 1990 to 2009 in Turkey. In 2001, the industrial sector had the largest share of final energy consumption. However, in 2009, the residential sector's share is more than the other sectors' shares. In the residential sector, large share of energy consumption stems from heating losses. Therefore, some precautions must be taken to improve energy efficiency in the residential sector.

Table 3.6. Energy Consumption by Sectors (Thousand Tons of Oil Equivalent (KToe))[29].

Years	Residential	Industrial	Transportation	Agriculture	Non-energy	Final energy consumption	Conversion sector	Total energy consumption
2000	20,058	24,501	12,008	3,073	1,915	61,555	18,945	80,500
2001	18,122	21,324	12,000	2,964	1,638	56,048	19,354	75,402
2002	18,463	24,782	11,405	3,030	1,806	59,486	18,845	78,331
2003	19,634	27,777	12,395	3,086	2,098	64,990	18,836	83,826
2004	20,252	29,358	13,907	3,314	2,174	69,005	18,814	87,818
2005	22,923	28,084	13,849	3,359	3,296	71,510	19,564	91,074
2006	23,677	30,996	14,994	3,610	4,163	77,441	22,201	99,642
2007	24,623	32,466	17,282	3,945	4,430	82,746	24,879	107,625
2008	28,323	26,906	15,996	5,174	3,244	79,642	26,779	106,421
2009	29,466	25,966	15,916	5,073	4,153	80,574	25,565	106,138

### 3.2.3. Electricity Outlook in the World

Electricity is a form of energy carrier which is obtained from primary and secondary energy carriers and it is indispensable for human life. It is the most needed energy form all over the World, and the demand for electricity is increasing each day with industrialization and globalization. However, there is a major disadvantage of electricity in that it is not storable. Since electricity cannot be stored, continuous supply and demand balance has to be ensured [24].

General information about world electricity generation is given in this subsection.

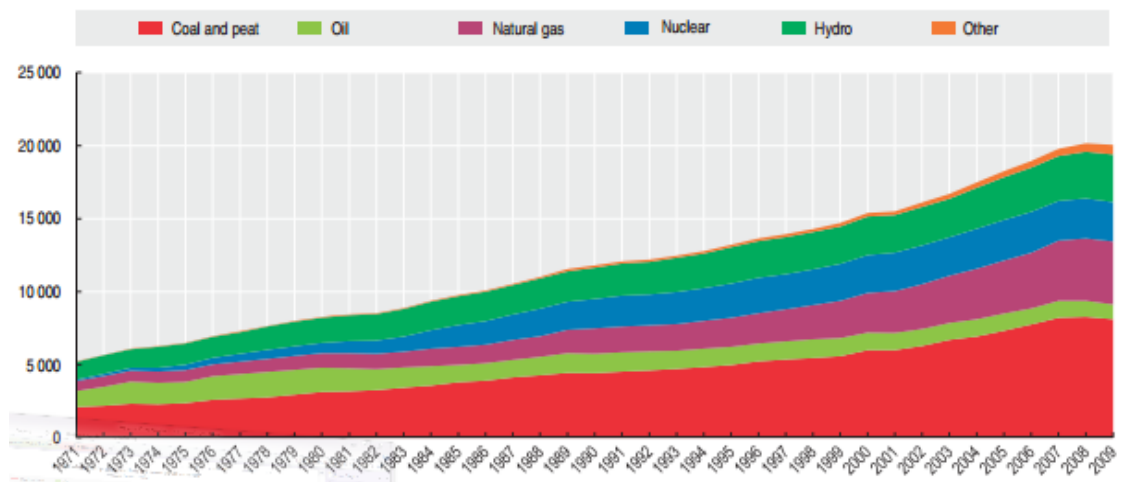


Figure 3.7. World electricity generation by source of energy Terawatt-hours (TWh) [31].

Average annual rate of increase in world electricity generation has been 3.6% from 1971 to 2009. The reasons of steady and continuous increases in global (and local) energy demand are, (i) development of and heavier reliance on electrical appliances, (ii) economic development, (iii) population increases, (iv) availability of electricity to more people through rural electrification projects [31].

The status of and changes in the profile of primary (and secondary) energy resources used in electricity generation is also quite interesting. The share of electricity generation from oil has sharply decreased from 20.9% (in 1971) to 5.1% (in 2009). There is also a decrease in the share of hydro from 22.9% to 16.2%. However, the share of nuclear has increased from 2.1% to 13.4% and the share of natural gas has increased from 13.3% to 21.4%. It is worthwhile to note that the share of coal and peat has remained stable at 40-41 % [31].

Electricity has an increasing share in the World total energy demand. The International Energy Agency (IEA) estimates that, in the period 2009-2010, there has been 5.4% increase in worldwide electricity demand and a 9.5% increase in non-OECD countries [26].

### 3.2.4. Electricity Outlook in Turkey

Table 3.7. Electricity energy production by resources in Turkey[32].

	Hardcoal		Lignite		Fuel Oil		Natural Gas		Biogas, Waste, Other		Thermal		Hydro		Geothermal and Wind		Total	
	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%
1990	621	1	19,560	34	3,942	7	10,192	18	-	-	34,315	60	23,148	40	80	-	57,543	100
1995	2,232	3	25,815	30	5,772	7	16,579	19	222	0	50,620	59	35,541	41	86	-	86,247	100
2000	3,819	3	34,367	28	9,311	8	46,217	37	220	0	93,934	75	30,879	25	109	0	124,922	100
2005	13,246	8	29,946	18,5	5,483	3	73,445	45	122	0	122,242	76	39,561	24	153	0	161,956	100
2010	19,104	9	35,942	17,0	2,180	1	98,144	47	457	0	155,828	74	51,795	25	3,585	2	211,208	100
2011	25,159	11	39,415	17,3	3,804	2	102,131	45	450	0	170,959	75	52,078	23	5,394	2	228,431	100

Table 3.7 shows the electricity generation by fuel types in Turkey from 1990 to 2011, which gives brief information about Turkey's energy resources.

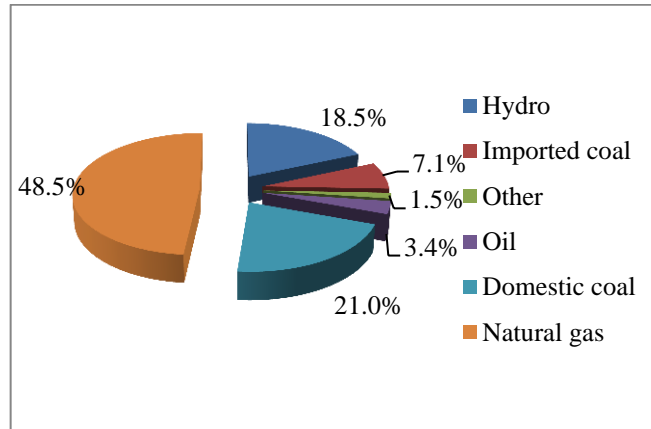


Figure 3.8. Turkey's electricity generation by fuels in 2008 [33].

The electricity generation by fuel type in 2008 is displayed in Figure 3.8. Natural gas is the leading fuel type in electricity generation with 48.5 %. The natural gas is followed by domestic coal with 21% of total electricity generation.

Table 3.8. CO<sub>2</sub> emissions from the energy and electricity sectors in Thousand Tonnes (kt) [34].

Sectors	1990	1995	2000	2005	2006	2007	2008	2009	2010
Energy	126,701	155,347	207,054	236,355	253,150	282,834	270,862	271,109	277,453
Electricity	30,325	43,750	72,089	83,680	85,312	100,662	101,473	96,286	106,824

The CO<sub>2</sub> emissions from the electricity sector has been 30,325 (kt) in 1990 and this amount is increasing year by year. The effects of the economic crisis in Turkey on energy sector in the year 2009 should also be noted (it has led to temporary reductions in electricity and GHG generation) [28].

Table 3.9. Turkey's Gross-Net Electricity Production, Import, Gross Electricity Consumption, Grid Losses and Export (GWh) from 2006 to 2010 [29].

Years	Gross Production	Increase in Gross Production	Net Production	Import	Gross Consumption	Increase in Gross Consumption	Grid Losses	Export
2006	176,300	-	169,543	573	170,116	-	4,544	2,236
2007	191,558	9%	183,340	864	184,204	8%	4,523	2,422
2008	198,418	13%	189,762	789	190,551	12%	4,388	1,122
2009	194,813	11%	186,619	812	187,431	10%	3,973	1,546
2010	211,208	20%	203,046	1,144	204,190	20%	5,691	1,918

Table 3.9 shows that electricity production and consumption is increasing each year except for the year 2009 (which is the year that Turkish economy has experienced a recession).

The total World electricity generation has been 22,018.1 TWh in 2011 and Turkey's electricity generation is about 1% of world electricity generation with 228.4 TWh. China, which has produced 4700.1 TWh of electrical energy in 2011, has the maximum share of world electricity generation with 11.7% [25].

### 3.2.5. Environmental Impacts of the Energy Sector in the World

Energy production and consumption have great impacts on the environment and public health since they emit greenhouse gases as well as many environmentally hazardous substances. Greenhouse gas emissions are generally caused by industrial processes and burning of fossil fuels, while renewable sources and nuclear based energy generation result in little greenhouse gas emissions.

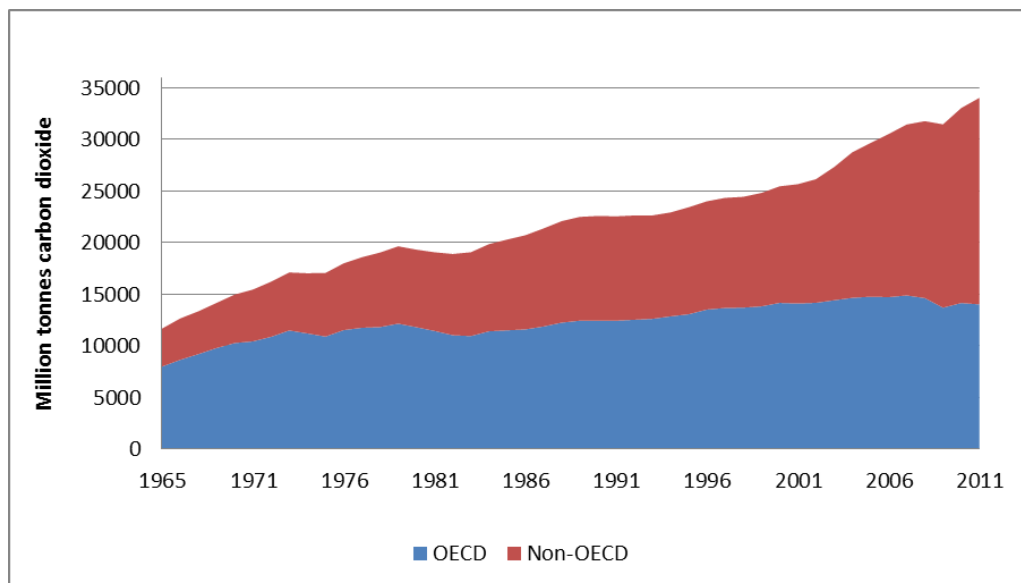


Figure 3.9. World (OECD and non-OECD) CO<sub>2</sub> emissions (1965-2011) [25].

The share of non-OECD countries in total CO<sub>2</sub> emissions is increasing each year as it can be inferred from Figure 3.9.

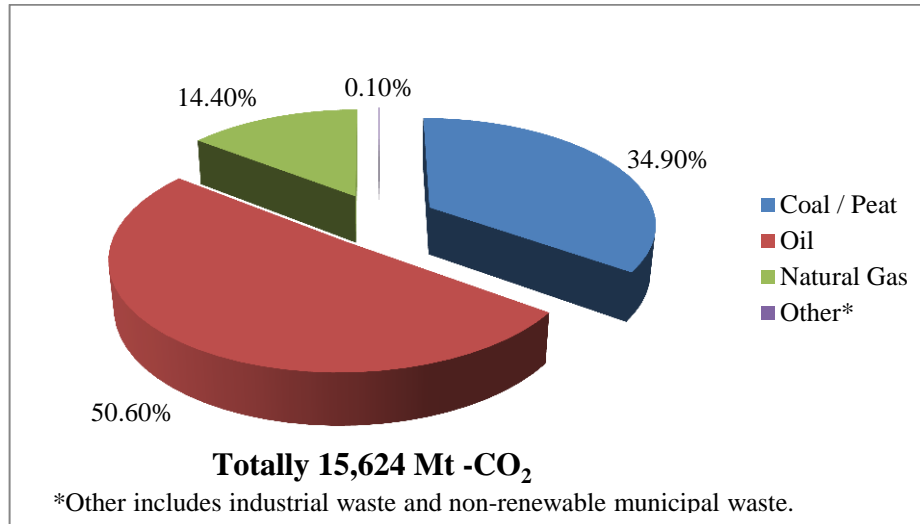


Figure 3.10. Primary energy resource shares in CO<sub>2</sub> emissions in the World in 1973 [27].

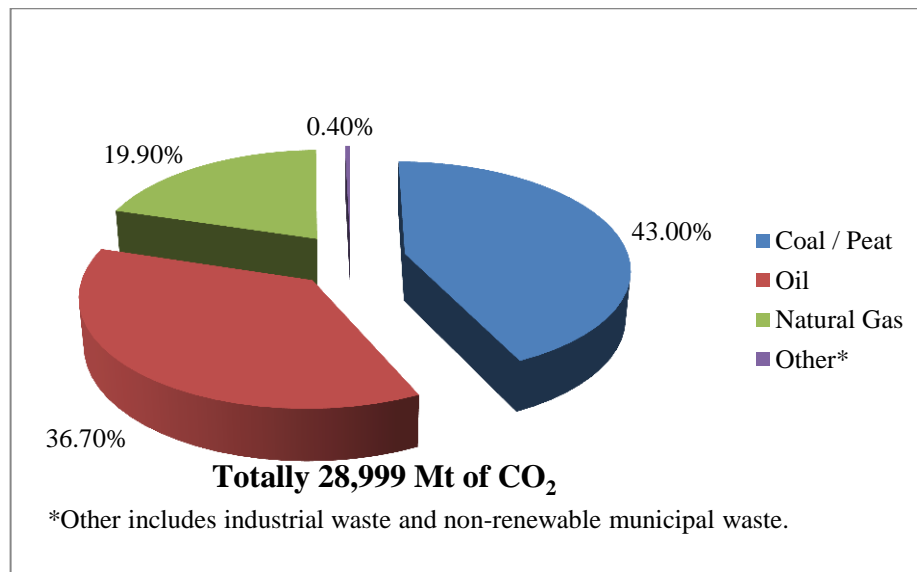


Figure 3.11. Primary energy resource shares in CO<sub>2</sub> emissions in the World in 2009 [27].

Figure 3.10 and 3.11 show the share of primary energy resources in CO<sub>2</sub> emissions in the year 1973 and 2009. Although oil has the largest share of CO<sub>2</sub> emissions in 1973 with 50.6%, its share has decreased in recent years. Coal/ peat has been the leading source of CO<sub>2</sub> emissions with 43% in 2009.

### 3.2.6. Environmental Impacts of the Energy Sector in Turkey

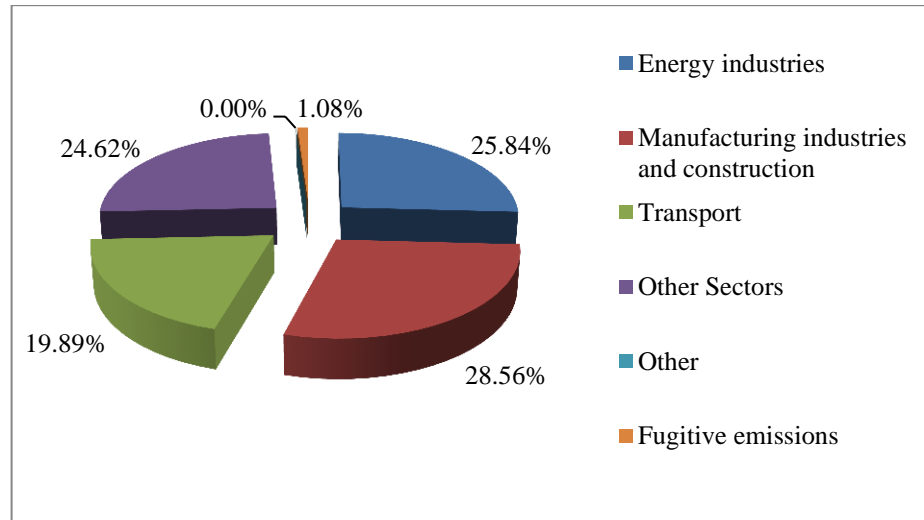


Figure 3.12. Breakdown of GHG emissions within the energy sector in 1990 [35].

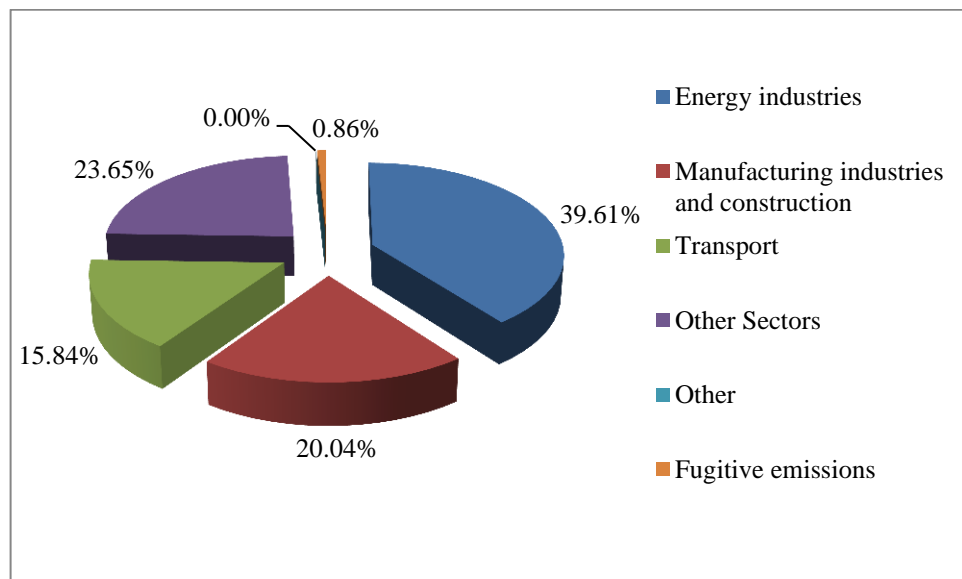


Figure 3.13. Breakdown of GHG emissions within the energy sector in 2010 [35].

In 1990, the largest share in energy sector belonged to manufacturing industries and construction, however, in 2010, energy industries have the largest share of GHG emissions within the energy sector. Since the energy demand is increasing day by day, almost every sub-sector of energy sector has grown each year. And the need for energy industries is getting higher, which are the largest CO<sub>2</sub> emitting sector in 2009. Also, it is worth

mentioning that the reason why energy industries emit such huge amounts of CO<sub>2</sub> emissions is the public electricity and heating production [36].

Table 3.10. Total greenhouse gas emissions by sectors in Turkey (1990-2009) [28].

<b>Sectors \ Years</b>	<b>1990</b>	<b>1995</b>	<b>2000</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>
<b>Energy</b>	132.13	160.79	212.55	241.75	258.56	288.69	276.71	278.33
<b>Industrial Processes</b>	15.44	24.21	24.37	28.78	30.70	29.26	29.83	31.69
<b>Agricultural Activities</b>	29.78	29.68	27.37	25.84	26.50	26.31	25.04	25.70
<b>Waste</b>	9.68	23.83	32.72	33.52	33.88	35.71	33.92	33.93
<b>TOTAL</b>	<b>187.03</b>	<b>238.51</b>	<b>297.01</b>	<b>329.89</b>	<b>349.64</b>	<b>379.97</b>	<b>365.50</b>	<b>369.65</b>

## **4. A DETAILED MARKAL MODEL OF THE TURKISH ELECTRICITY SECTOR**

In Turkey, as a fast developing country, demand for energy is growing each day. As energy's strategic importance regarding sustainable economic growth, social and political stability and for local and global environmental impacts becomes more of an issue, an energy modeling system that balances long and short term energy supply and demand identifies possible bottlenecks coordinates investments and financing and foresees environmental impacts, in scenario based frameworks becomes inevitable.

As mentioned in the first chapter of this study, there already exists a basic bottom-up energy modeling system, the MARKAL-Turkey Energy model. Additionally, in other previous studies, the transportation and industry sectors of the basic MARKAL-Turkey model are expanded and refined. In this study, another key sector of the energy system, the electricity sector, is analyzed and this primary module of the MARKAL-Turkey model is expanded and elaborated.

Electricity is indispensable in our daily lives and it is the most prevalent energy form. After conversion of various primary and secondary energy resources into electricity, it becomes a key final energy carrier that satisfies end users' energy demand. Electricity is used in many part of daily lives; for instance, in communication tools, security systems, household appliances, office appliances, etc. As technological development driven economic development proceeds, the reliance on electric power increases. Accordingly, its strategic importance gets greater with rapid industrialization. The consumption of electricity energy has become an indicator of economic development of a country. That is why the electricity sector is the key element in energy system.

In this chapter, the technology options in the MARKAL-Turkey Electricity Model and related model data (such as investment, fixed and variable operating and maintenance costs, availability, life time, etc.) are presented and discussed in depth. Some of the data is

acquired from public and private organizations (including EÜAŞ, TÜİK and EMO); and some of the data is obtained from the global literature.

The following section gives brief information for all energy resources and technology options deployed in the MARKAL-Turkey model's electricity sector.

#### 4.1. Hydro Energy

Hydro is one of the most significant energy resources in Turkey. After coal, hydro energy is the second largest domestic energy resource in Turkey. The potential of hydro energy is 129.4 billion KWh/year [37]. As of 2011, the total installed hydro power capacity is 17,137.1 MW and its share in the total installed electricity generation capacity of Turkey is 32.2 %. The share of hydro energy in electricity production is 25.2 % with 57,472 GWh [32].

Table 4.1. The share of hydro electricity generation over total electricity generation (GWh) [32].

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
<b>Total Electricity Generation</b>	122,725	129,400	140,581	150,698	161,956	176,300	191,558	198,418	194,112	210,120	228,431
<b>Hydroelectricity Generation</b>	24,010	33,684	35,330	46,084	39,561	44,244	35,851	33,270	35,905	51,505	57,472
<b>Share of Hydroelectricity %</b>	19.6	26	25.1	30.6	24.4	25.1	18.7	16.8	18.5	24.5	25.2

For the purpose of improving hydro electricity generation potential, Renewable Energy Resources for the Generation of Electrical Energy Law (Law No.5346 ), has come into force in 2005 . This law encourages to establish and operate new hydro power plants in recent years [38]. After the ratification of this law, especially, channel and small river dams type of hydroelectricity power plants (which are small sized) have been increasing. Accordingly, there is a noticeable increase in the share of hydroelectric power generation after 2009.

Table 4.2. The technical and economic potential of Turkey's hydro electricity generation in 2010 [32].

<b>Hydro Power Plants</b>	<b>Installed Capacity - MW (2009)</b>	<b>Installed Capacity - MW (2010)</b>	<b>Average Annual Generation Capacity (GWh/year)</b>
<b>Operating</b>	14,254	16,400	49,700
<b>Under Construction</b>	8,046	12,841	18,300
<b>Planned</b>	22,700	15,709	72,000
<b>Total</b>	45,000	45,950	140,000

Hydro power plants are grouped according their capacities. The capacity selection is primarily dictated by environmental, geographic and physical factors and limitation. However, there are also different advantages of each kind of hydro power plants. For instance, building small scale hydro electricity generation plants are fast and less costly ways for providing electricity to remote villages that are not close to transmission lines [39].

In this study, hydro energy is grouped into four main categories. The first one is large scale hydro power plants whose installed capacity is greater than 100 MW. The second group is medium scaled power plants whose installed capacity is between 20 MW and 100 MW. Third group is small scaled power plants whose installed capacity is between 1.25 MW and 20 MW. And finally, the fourth group is micro scaled hydro power plants whose installed capacity is lower than 1.25 MW. Each of these four groups are further categorized into 2 subgroups as privately and publicly owned hydro power plants. Life span of hydro power plants is about 40 years [40]. The average availability of these hydro power plants is about 40% [41]. These new technologies are determined while taking into account their installation rate in the World and the likelihood of applying these technologies in Turkey.

## **4.2. Wind Energy**

Wind energy is another important energy resource that utilized in electricity generation sector in the MARKAL- Turkey model. Turkey has a large wind energy

potential to generate electricity. The Marmara, South East Anatolian, and Aegean Regions are the most favorable places for utilizing wind energy [42]. The studies conducted in Turkey point out that the average annual wind speed is 2.5 m/sec and the annual wind power density is 2.4 watt/ m<sup>2</sup>. The main disadvantage of wind energy is its intermittent availability and frequent maintenance needs. Accordingly, its investment and maintenance costs are higher compared to those of fossil fuel energy resources. However, its operating costs are relatively lower. Turkey aims to have 10 GW in installed wind energy capacity in 2015 and reach to 20 GW in 2023, in the framework of the Energy Strategy Plan [43].

Table 4.3. Wind power potential [44].

Wind Source Degree	Wind Power Class	Wind Power Density at 50 m (W/m <sup>2</sup> )	Speed at 50 m (m/s)	Total Area (km <sup>2</sup> )	Windy Land Share (%)	Total Installed Capacity (MW)
Medium	3	300 - 400	6.5 - 7.0	16,781.39	2.27	83,906.00
Good	4	400 - 500	7.0 - 7.5	5,851.87	0.79	29,259.36
Wonderful	5	500 - 600	7.5 - 8.0	2,598.86	0.35	12,994.32
Excellent	6	600 - 800	8.0 - 9.0	1,079.98	0.15	5,399.92
Extraordinary	7	> 800	> 9.0	39.17	0.01	195.84
<b>Total</b>				26,351.28	3.57	131,756.40

The installed capacity for wind energy is increasing each year. Especially, after 2005, there is a remarkable improvement in the utilization of wind energy. As can be seen in Figure 4.1, while the total installed capacity for wind energy was 146.3 MW in 2006, it has arisen to 1,358 MW in 2011 [45]. The underlying reason of this gradual increase in recent years is incentives on utilization of renewable energy resources that come into force in 2005.

As of 2011, the wind energy's share in Turkey's electricity production is 2.1% [46]. On the other hand, almost 3.6% of Turkey's land mass (nearly 26,350 km<sup>2</sup>) enjoys sufficient wind power that has the potential for electricity generation. In this study, wind energy is divided into 2 groups since there are some differences in wind energy technologies: onshore and offshore wind energy technologies. The onshore wind energy technology is also divided into subgroups according to the design wind speed. The available onshore wind energy technologies are in 5 subgroups, namely 6.5-7 (m/sec), 7-7.5 (m/sec), 7.5-8 (m/sec), 8-9 (m/sec), and greater than 9 (m/sec) wind speeds at 50 m

high. These technologies are considered while taking into account their installation rate in the World and the likelihood of applying these technologies in Turkey.

The investment costs of offshore wind energy facilities (range from 1200 €/kW to 2700 €/kW) are higher than the investment costs of onshore facilities (range from 1100 €/kW to 1400 €/kW) [47]. The average lifetime for wind turbines is 25 years [48]. Currently offshore wind accounts for a small portion of total installed wind power capacity over the world. However, its share (both globally and in Turkey) is expected to grow.

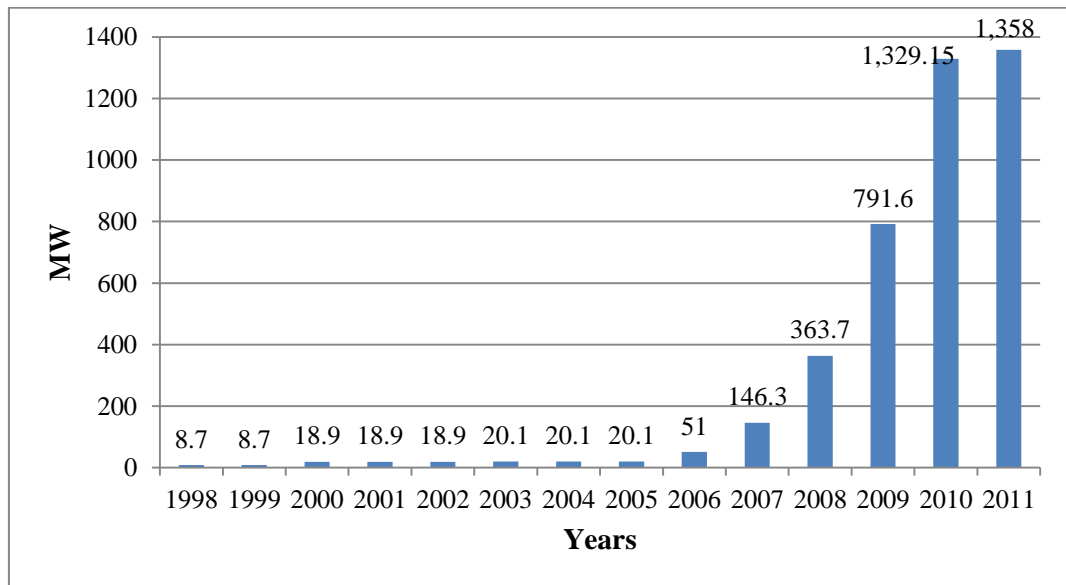


Figure 4.1. The installed capacity for wind energy from 1998 to 2010 in Turkey [44].

### 4.3. Geothermal Energy

Geothermal energy is the heat energy stored in the Earth mass and which has naturally found its way to the surface (or near to surface) through the faults in the Earth's geological layers, in the form of steam, hot water and/or hot gases. It is a clean, sustainable and renewable energy type. Because of its geologic and tectonic structure, Turkey has a large potential for geothermal energy such that it is one of the top countries in world regarding geothermal usage ranking [25]. Geothermal energy is expected to play a significant role in Turkey's future renewable energy resource supply. Its resources are utilized for both electricity and heat generation in the MARKAL Turkey model.

Turkey's geothermal capacity is 600 Mega Watt electrical (MWe) for electricity and 31,500 Mega Watt thermal (MWt) for heat production [44]. According to the studies carried out by the General Directorate of Mineral Research and Exploration (MTA), there are about 1500 hot and mineral water resources with temperatures ranging from 20 °C to 242 °C in Turkey.

Currently, about 11,000 residence equivalents, 2,300,000 m<sup>2</sup> of agricultural greenhouse and 260 spas are heated by geothermal energy [44]. The West Anatolia, namely Denizli-Kızıldere, Aydın-Germencik, and Kütahya-Simav are the most prominent locations for geothermal energy [49].

The average lifespan for geothermal power plants is 40 years [50]. The total installed capacity is displayed in Table 4.4 by the years. The change in installed geothermal power capacity from 2010 to 2011 is noteworthy. The reason of this change is the establishment of new geothermal power plants in 2010.

In the MARKAL-Turkey model, geothermal energy is divided into 2 main groups: Geothermal for electricity generation and geothermal for heat generation. The related technologies are determined while taking into account their installation rate in the World and the likelihood of applying these technologies in Turkey.

Table 4.4. The installed geothermal power capacity (MW) for Turkey and World (1975-2011) [25].

	1975	1980	1985	1990	1995	2000	2005	2010	2011	Change 2011 over 2010	2011 share of total
<b>Turkey</b>				21	20	20	20	94	114	21.20%	1.00%
<b>Total World</b>	1,300	3,887	4,764	5,943	6,767	8,077	9,134	10,926	11,014	0.80%	100.00%

#### 4.4. Solar Energy

Due to the detrimental effects of fossil fuels on environment; solar energy, which is one of the renewable energy resources, is being seriously considered to help meet future energy demand in Turkey [51].

Solar energy is utilized for heating or generating electricity power. Turkey has a significant solar energy potential since its geographical location is between 36° and 42 °N latitudes and she has a typical Mediterranean climate [51]. The meteorological data shows that the average annual solar irradiance intensity is 308 cal/cm<sup>2</sup>-3.6 KWh/m<sup>2</sup> per day and the average annual sunshine duration is 2640 hours in Turkey [52]. The solar energy potential in Turkey is 32.6 MToe and 56,000 MW. The total installed capacity in Turkey is almost 0 GW in 2006 and 2011 [53,54]. Table 4.5 provides some information about solar energy in Turkey.

The solar energy technologies considered in the MARKAL–Turkey model are photovoltaic power generation technologies which are grouped under residential and commercial PV technologies. In addition, solar pool technologies are added to the model. These technologies are determined while taking into account their installation rate in the World and the likelihood of applying these technologies in Turkey. The average lifespan for solar power technologies is 20 years [55].

Table 4.5. Average solar energy potential of Turkey and insolation durations on monthly basis [56].

Months	Total monthly solar energy		Insolation duration (h/month)
	kcal/cm <sup>2</sup> -month	kWh/m <sup>2</sup> -month	
January	4.45	51.75	103
February	5.44	63.27	115
March	8.31	96.65	165
April	10.51	122.23	197
May	13.23	153.86	273
June	14.51	168.75	325
July	15.08	175.38	365
August	13.62	158.40	343
September	10.60	123.28	280
October	7.73	89.90	214
November	5.23	60.82	157
December	4.03	46.87	103
<b>Total</b>	112.74	1,311.00	2,640
<b>Average</b>	0.31 kcal/cm <sup>2</sup> -day	3.6 kWh/m <sup>2</sup> -day	7.2 h/day

#### 4.5. Bio-Power energy

Another renewable energy source in Turkey is bio-energy. Biogas is caused by biomass and consists of methane (CH<sub>4</sub>), CO<sub>2</sub>, nitrogen, hydrogen, and oxygen. Biogas generation from garbage is a good example of biogas utilization in Turkey [44, 57]. Turkey has at least 4000 MW biogas potential. Another bioenergy resource is biodiesel which is obtained from agricultural crops or from recycled restaurant greases. It can be used in pure form or blended with diesel. It is called according to fuel mix such that 100% biodiesel is called B100, 20% biodiesel with 80% petrodiesel is called B20, 5% biodiesel with 95% petrodiesel is called B5, and 2% biodiesel with 98% petrodiesel is called B2 [58]. There is also bioethanol which is obtained from plant-based feedstocks by fermentation [59]. It is blended with gasoline. The most common ones are E-10 (10% bioethanol and 90% gasoline) and E-85 (85% bioethanol and 15% gasoline) [60]

Table 4.6. Renewable Resources in Turkey (2011) [44].

Source	Potential	Under Construction	Operating
<b>Hydro</b>	45,000 MW	14,600 MW	16,160 MW
<b>Wind</b>	48,000 MW	2,130 MW	1,360 MW
<b>Solar</b>	300 TWh/Year	-	-
<b>Geothermal</b>	600 MW	118 MW	94 MW
<b>Bioenergy</b>	17 Mtoe	50 MW	97 MW

In 2006, the installed power is for digester gas was 7 MW and for landfill gas was 5.5 MW [61]. The installed power for biomass technologies in 2011 reached 63 MW [62]. The expected life cycle for bio-energy power plants range from 15 to 20. The expected life cycle for biomass power plants is 20 years [63]. The availability of these technologies is higher than 60% [64].

The bio-energy technologies of the electricity sector in the MARKAL Model are grouped according to fuel types and then sub grouped according to technology types. The biogas plants are grouped according to those using “Steam Turbine” and “Slurry Digester” technologies. The biogas technologies are “Renewable Agri Waste Combustion Plants (Steam Turbine) Plants” and “Renewable Agri Waste Slurry Digester”. The plants that use biomass are “Energy crop gasification technologies for 2010, 2020, 2030 and 2040” and “Gas driven Gas Turbine Combined Cycle”. The plants that use landfill gas is “Landfill gas driven with Internal Combustion Engine”. These technologies are determined while taking into account their installation rate in the World and the likelihood of applying these technologies in Turkey.

#### **4.6. Nuclear Power**

In the last few decades, many countries have moved into or at least seriously considering and planning nuclear power generation. Due to the absence of indigenous natural energy resources, such as coal and oil, some countries such as France and Japan, have been strongly supporting and encouraging the utilization of nuclear power systems [65].

There are various advantages of nuclear energy. For instance, since it generates almost no greenhouse gases, the utilization of nuclear power plants instead of coal fired power plants results in reducing CO<sub>2</sub> emissions to atmosphere [66].

In Turkey, there is no nuclear power plant in operation. However, it is planned to construct a 4800 MW nuclear power plant at Akkuyu [67]. The planned power reactor type is VVER-1200 with 1200 MWe gross. The state also has plans about constructing other nuclear power plants. The planned reactor types are depicted in Table 4.6.

Table 4.7. Planned and proposed nuclear power reactors [68].

<b>Location</b>	<b>Type</b>	<b>MWe Gross</b>
Akkuyu 1	VVER-1200	1,200
Akkuyu 2	VVER-1200	1,200
Akkuyu 3	VVER-1200	1,200
Akkuyu 4	VVER-1200	1,200
Sinop 1	APWR (Proposed)	1,550
Sinop 2	APWR (Proposed)	1,550
Sinop 3	APWR (Proposed)	1,550
Sinop 4	APWR (Proposed)	1,550

Currently, Turkey depends heavily on imported natural gas (mostly from Russia and Iran) to generate electricity. It is claimed that with the nuclear power generation, Turkey will depend less on imports. Besides, World Nuclear Association claims that utilization of nuclear power energy not only reduces the problem of energy dependence, but also helps the economy grow [67].

The technology options considered in the model for nuclear power energy are grouped according to the reactor types in the nuclear power plants. The technologies are : Advanced Gas Cooled, AP1000(URN), EPWR (URN), GTMH, Magnox, Pebble Bed and PWR Reactors. These technology options are determined while taking into account their installation rate in the World and the likelihood of applying these technologies in Turkey.

#### **4.7. Hydrogen Energy**

Hydrogen energy, which is an alternative energy resource, has highest energy content per unit mass and emits almost no pollution. The amount of energy in 1 kg of hydrogen is equivalent to energy in 2.1 kg of natural gas and 2.8 kg of petroleum [69]. Besides, it should be mentioned that hydrogen is an important energy carrier like electricity because it is possible to deliver hydrogen energy to the areas where a consumer need it. However, it is costly and there is no hydrogen energy based technology in Turkey except for a few prototypes [70].

The hydrogen technologies in the MARKAL model are “Residential Hydrogen driven microfuel cell”, “Residential Hydrogen driven microfuel cell for 2020”, “CHP with

PEMFC” and “CHP with PEMFC 2020”. Hydrogen fuel cells produce electricity, heat and water while using hydrogen as fuel [71]. These new technologies are determined while taking into account their installation rate in the World and the likelihood of applying these technologies in Turkey.

The average life time for power plants is 20-30 years, and their availability is about 90% [72].

#### 4.8. Coal

Coal is one of the most important fossil fuels for electricity generation all over the world and it seems that its importance will continue. In Turkey, coal is mostly used in power generation, steel manufacturing, and cement production. It has the largest share of consumed fuel types. Afşin-Elbistan, Muğla, Soma, Tunçbilek, Seyitömer, Beypazarı and Sivas reserves are the most significant lignite reserves in Turkey. Besides, Zonguldak basin has the most important reserves of hard coal. Nevertheless a significant share of the coal consumption is provided from imports, since lignite excavated in Turkey has low energy value (the calorific value of domestic lignite varies between 1,000 kcal/kg and 4,200 kcal/kg) [73].

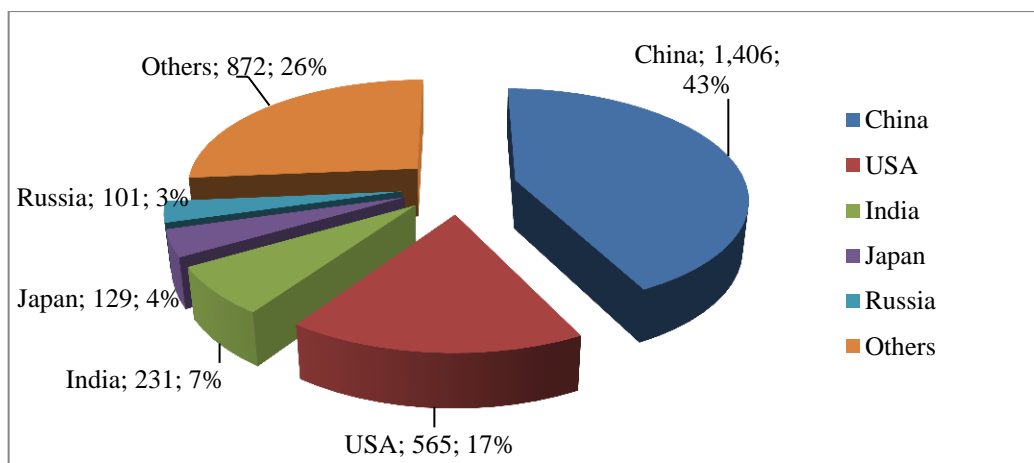


Figure 4.2. World coal consumption (Mtoe, percentage) [33].

The world's total coal consumption has been about 3.3 Billion Tons of Oil Equivalent (Billion Toe) in 2008. As it can be inferred from Figure 4.2, China and the USA are the top two coal consumers, whose shares are 43% and 17% respectively. Also, it is predicted that world coal demand will reach to 10 billion toe until 2030. Besides, it should be mentioned that about 90% of the world's coal export is realized by the following 7 countries: Australia, Indonesia, Russia, Colombia, South Africa, China and the USA [33].

Moreover, 70% of the coal is consumed to produce electricity. The rest is consumed primarily in space heating, iron-steel and cement industry sectors. Coal is the common fuel used for generating electricity worldwide such that it had the maximum share with 41.5% in 2007.

In 2008, the share of coal in Turkey's primary production was 57.1%. At that time, the domestic coal share in Turkey's primary energy consumption was 15.5% [33]. Additionally, the lignite production in Turkey is 66.7 million tons and the hard coal production is 2.9 million tons, which equals a total of 69.6 million tons of coal. The total capacity of installed coal power plants were 10,197 MW in 2006 and 12,491 MW in 2011 [74]. The primary energy consumption of hard coal and lignite were 22.7 and 60.1 million tons, respectively in 2006 [29]. The lifespan of coal fired power plants is about 30 years [75].

In this study, coal based technologies are grouped according to their capacities: "Large coal plants (whose capacity is greater than 1000 MW)", "Medium coal plants (whose capacity is between 500 and 1000 MW)", and "Small coal plants (whose capacity is lower than 500 MW)". These small coal plants are also categorized into subgroups: Small Coal-Lignite Plants that are publicly owned, Small Coal-Bituminous Plants that are publicly owned and Small Coal-Lignite plants that are privately owned and Small Coal-Bituminous plants that are privately owned. Besides, there also exist new coal fired technologies that are subgrouped without considering their scale. These new technologies are : New Co-firing coal plant 2020", "New Co-firing coal plant with carbon capture for 2015 and 2020", "New coal plants with IGCC for 2020", "New coal plants with IGCC for 2030", "New coal plants with IGCC and carbon capture for 2020", "New coal plants with

IGCC and carbon capture for 2030”, “New coal fired PF Plant for 2020”, “New coal fired PF Plant for 2030”, “New coal fired PF Plant for 2020”, and “New coal fired PF Plant for 2030”. Also, there exists a technology “Coal fired CHP plants with steam turbine” for coal fired heat and power plants. These technologies are determined with taking into account their installation rate in the World and possibility to apply these technologies in Turkey.

#### **4.9. Heavy Fuel Oil**

Oil consists of many sub products such as natural gas liquids, refinery feed stocks, hydrocarbons and petroleum products (heavy fuel oil, naphta, lubricants, etc.). Most of the oil products are used in different energy sectors (such as transportation, agriculture and industry). However only heavy fuel oil and diesel are deployed in electricity generation.

Heavy fuel oil is acquired by petroleum distillations [76,77]. Heavy fuel oils are commonly used in large diesel engines or boilers, commercial and industrial heating. Besides, they are used in the plants that generate electricity, heat or both of them [78].

The diesel based technologies (diesel power plants) in the MARKAL-Turkey model are called “Diesel Engine” and “Diesel Engine Private”. And the technologies which are relevant to heavy fuel oil are “Oil fired plants with steam turbine”, “Dual oil fired plants with steam turbine” , “Oil fired plants with IGCC for after 2010”, “Oil fired plants with IGCC for 2020”, “Oil fired plants with IGCC for after 2040” and “Oil fired plants with CHP”. These new technologies are determined while taking into account their installation rate in the World and the likelihood of applying these technologies in Turkey.

The average life time for heavy fuel oil fired power plants is 20-30 and their availability is about %60-80 [79].

#### **4.10. Natural Gas**

Natural gas has the second largest share in world electricity generation after coal, accounting for 15.6% in 2007 [33]. In Turkey, its consumption has been fast growing in

the last two decades and as of 2010, its share in electricity generation and total energy consumption is 48% and 31.9%, respectively.

Table 4.8. The shares of resources in total energy consumption between 1975 and 2010 in Turkey (%) [80].

	1975	1980	1985	1990	1995	2000	2005	2010
<b>Natural Gas</b>	0	0.1	0.2	5.9	9.9	17.1	27.3	31.9
<b>Oil</b>	51.7	50.3	46	45.1	46	40.1	35.2	26.7
<b>Coal</b>	21.5	22.1	21.4	30.9	27.2	30	26.4	30.6
<b>Hydro</b>	1.9	3.1	2.6	3.8	4.8	3.3	3.7	4.1
<b>Others</b>	24.9	24.4	29.8	14.3	12.1	9.5	7.4	6.7

Unfortunately, about 2% of the natural gas consumption in Turkey is met by domestic production. The rest of the natural gas demand is met by imported natural gas (imported primarily from Russian and Iran) [80]. The average life time for natural gas fired plants is about 25 years and the installed capacity for natural gas is 18,174 MW [75,54].

The natural gas based technologies considered in the MARKAL model are firstly grouped according to the capacities and technology types.

- “Publicly owned large plants (whose capacity is greater than 100 MW) with Gas turbine and combined cycle”,
- “Privately owned large plants (whose capacity is greater than 100 MW) with combined cycle”,
- “Privately owned large plants (whose capacity is greater than 100 MW) with gas turbine”,
- Privately owned large plants (whose capacity is greater than 100 MW) with gas turbine combined cycle”,
- “Medium plants (whose capacity is between 20 and 100 MW) with gas turbine and combined cycle”,
- “Medium plants (whose capacity is between 20 and 100 MW) with gas turbine steam sendout”,
- “Small plants (whose capacity is between 12 KW and 20 MW) with gas turbine”,

- “Small plants (whose capacity is between 12 KW and 20 MW) with steam turbine”,
- “Micro natural gas fired plants (whose capacity is lower than 120 KW) with gas turbine”,
- “Natural gas fired plants with gas engine”,
- “Natural and synthetic gas fired plants with combined cycle”,
- “New natural gas fired plants with GTCC for 2020”,
- “New natural gas fired plants with GTCC for 2030”,
- “New natural gas fired plants with GTCC and carbon capture for 2020”,
- “New natural gas fired plants with GTCC and carbon capture for 2030”,
- “New natural gas fired plants with GTCC and carbon capture for 2040”,
- “Natural gas driven with MCFC and CHP”,
- “Natural gas fired CCGT and CHP plant for industrial”,
- “Natural gas fired CCGT and CHP plant for district heating ”,
- “Natural gas driven with SOFC for 2020”,
- “New natural gas fired plants with gas engine”.

These technologies are determined while taking into account their installation rate in the World and the likelihood of applying these technologies in Turkey. Especially, the most prominent and prevailed technologies are natural gas fired GTCC CHP plant technologies. In these natural gas fired “combined cycle” power plants, there is both gas turbine and steam unit. Since heat energy released from the natural gas is efficiently used, these technologies are more advantageous than steam units or gas turbine alone [81]. Especially, with carbon capture technology, natural gas fired combined cycle technology takes more attention in future.

## **5. SCENARIOS AND THEIR RESULTS**

The expanded MARKAL-Turkey model is run under various scenarios and the obtained results (under each scenario), regarding energy resource, technology use, investments, costs, and emissions (over the planning horizon) are compared. In all scenarios the planning horizon is taken as from 2006 to 2051 at 5 year intervals. 2006 and 2011 are the calibration years for the model and in these periods model parameters are calibrated such that results are in line with the real conditions for Turkey. In these calibration years, the scenarios are not free to take any random values. Technology related parameters, exported and imported quantities, etc. are all set at their actually realized values [9]. The expansion of the electricity generation sector and enriched technology options mentioned in the previous chapter are included in the base scenario as well as the other scenarios. The following subsection describes the considered scenarios and the obtained results.

### **5.1. The Base Scenario**

The base scenario (also called the business as usual scenario) is the dataset that shows an energy system under prevailing conditions with no major policy changes in the future periods [9]. In this section the base scenario (namely “BASE”) is taken as reference scenario for the scenario analyses. Also, the results of the BASE scenario are compared to the results of previous study’s base scenario which is called the BAUSOLF scenario. The overall CO<sub>2</sub> emissions level, energy consumptions by key resources, and (discounted) costs over the planning horizon for the original and expanded MARKAL-Turkey model are presented in the following figures. The costs that are given in these results are in unit of million pounds (M pounds) with the prices of year 2000.

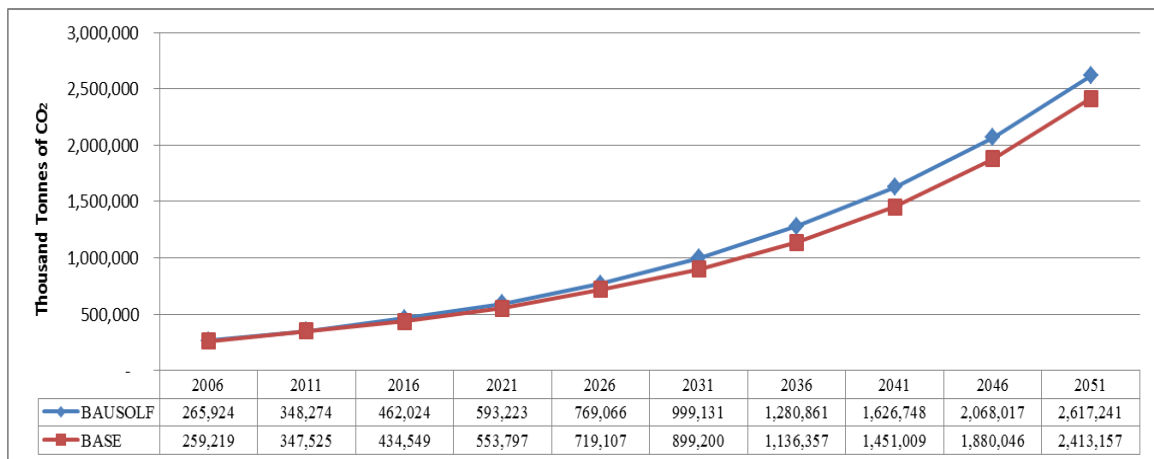


Figure 5.1. Total CO<sub>2</sub> emissions of all sectors in the BASE and the BAUSOLF scenarios.

As illustrated in Figure 5.1, there is a (very much expected) rise in the level of CO<sub>2</sub> emissions over the planning horizon. The overall CO<sub>2</sub> emissions level is 55,152,000 (kt) for the BAUSOLF and 50,587,000 (kt) for the BASE scenarios. The main reasons behind the around 5% reduction in GHG emission levels (at the end of the planning horizon) are, (i) the detailed considerations of electricity generation technologies, (ii) additional data compiled in GHG emissions of electricity generation technologies, (iii) changing discount rate from 10% to 5%.

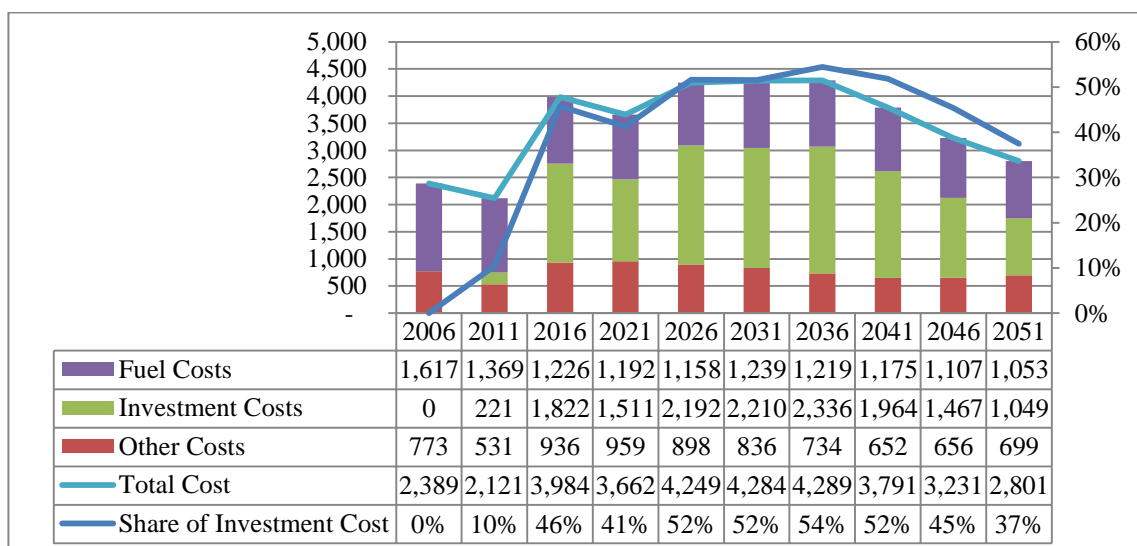


Figure 5.2. Costs of the electricity sector in the BASE scenario (M pounds).

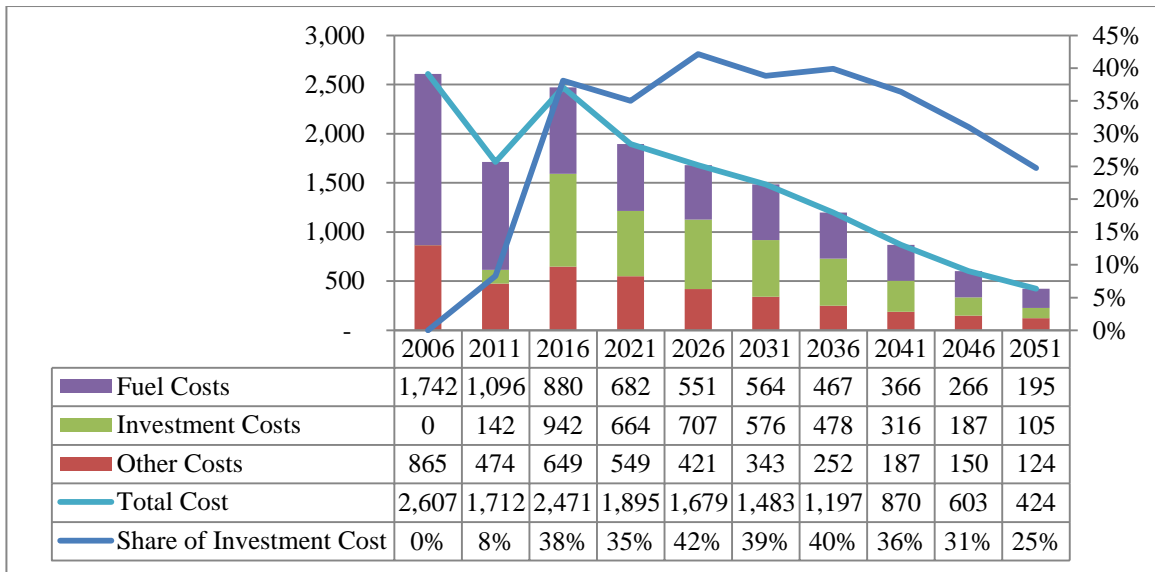


Figure 5.3. Costs of the electricity sector in the BAUSOLF scenario (M pounds).

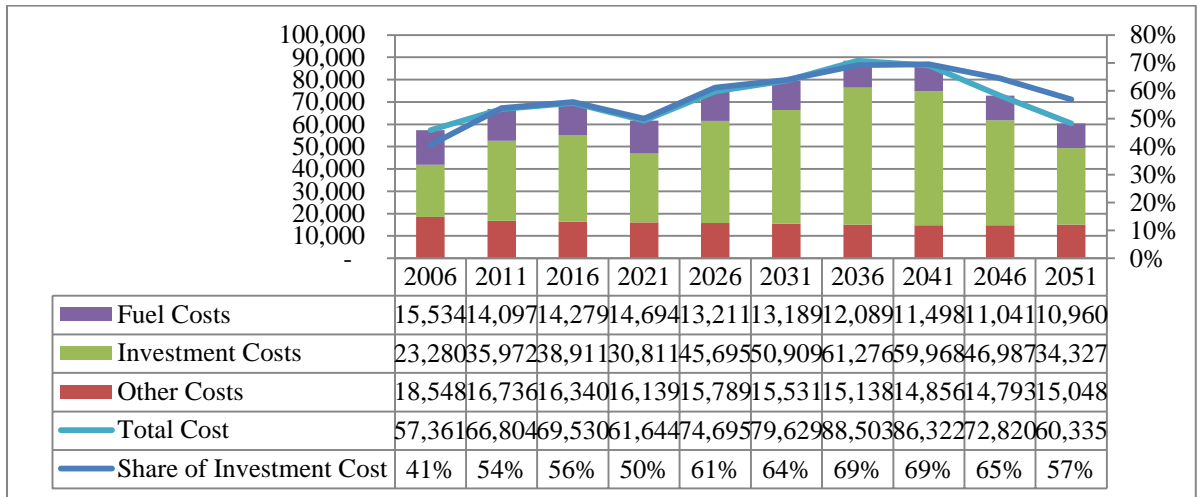


Figure 5.4. Costs of all sectors in the BASE scenario (M pounds).

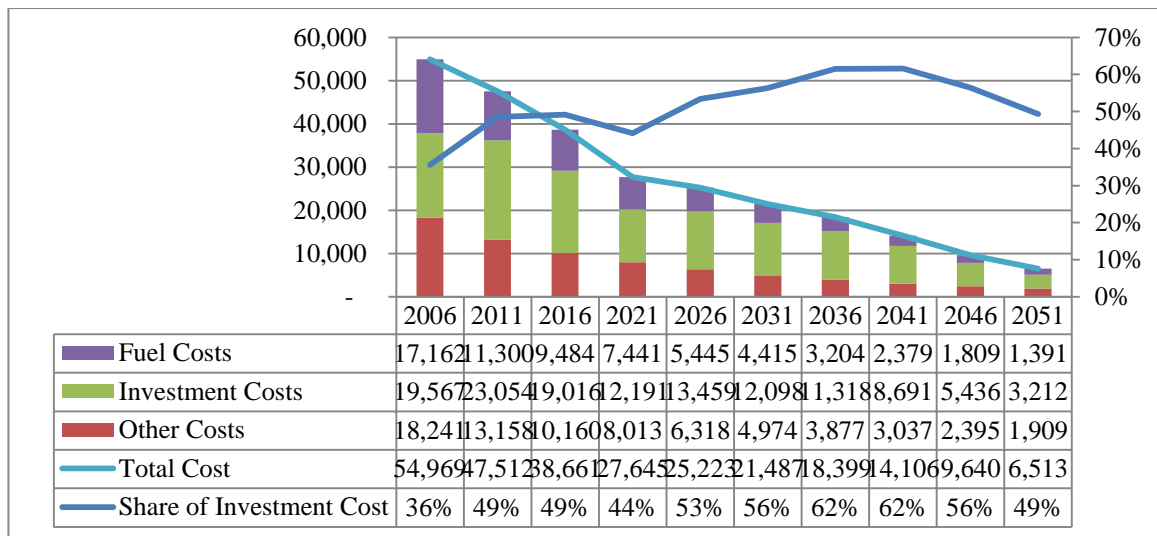


Figure 5.5. Costs of all sectors in the BAUSOLF scenario (M pounds).

There is a big difference between the costs estimated in the BASE and the BAUSOLF scenarios, especially towards the end of the planning horizon. The main reason of this difference is different discount rates. In the BAUSOLF scenario, the discount rate was chosen as 0.1. However, in the current BASE scenario, the discount rate is chosen as 0.05.

Table 5.1. Energy consumptions of the all sectors by resources in the BAUSOLF scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
COAL	1,214.7	1,681.1	2,897.2	4,090.9	5,881.0	8,177.0	11,280.6	14,925.3	19,377.6	24,838.0
DIESEL	582.6	617.7	658.9	732.2	802.9	928.6	785.7	631.8	412.5	185.7
HYDRO	164.8	144.4	124.1	124.2	124.3	107.7	114.4	116.5	113.0	111.8
GEOTHERMAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NATURAL GAS	1,253.0	1,323.7	1,000.0	1,000.0	788.5	615.8	383.9	343.3	511.9	691.6
OIL	95.6	1,126.7	1,201.4	1,335.2	1,464.2	1,693.4	1,432.7	928.2	809.7	0.0
SOLAR	24.3	15.1	9.4	5.8	3.6	2.2	1.4	0.9	0.5	0.3
WIND	0.4	1.2	1.2	1.2	1.2	0.0	0.0	0.0	0.0	0.0
BIO ENERGY	178.7	111.0	68.9	42.8	26.6	16.5	10.2	6.4	4.0	2.5
ANNUAL TOTAL	3,514.0	5,020.9	5,961.1	7,332.3	9,092.3	11,541.3	14,008.8	16,952.3	21,229.2	25,830.0



Table 5.5 Energy consumptions of the electricity sector by resources in the BASE scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	6.1	5.1	1.6	0.9	0.0	0.0	0.0	0.0
COAL	571.3	551.9	837.4	832.2	1,668.6	2,357.6	3,216.1	4,379.4	5,700.3	7,246.5
DIESEL	3.7	4.7	1.5	1.6	1.1	0.6	0.1	0.1	0.1	0.1
GEOTHERMAL	1.3	10.1	10.5	10.9	11.3	11.7	10.4	9.2	7.2	6.1
HEAVY FUEL OIL	39.3	4.5	9.9	107.3	7.1	11.5	0.7	0.7	0.7	0.3
HYDRO	218.5	200.4	200.4	200.4	182.3	182.3	166.9	145.6	130.7	124.6
NATURAL GAS	493.8	735.0	481.3	803.6	660.4	648.2	553.4	548.2	544.3	559.2
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	72.0	82.5	78.9	87.2	83.5	26.3	10.9	10.9
ANNUAL TOTAL	1,328.0	1,527.7	1,619.1	2,043.5	2,611.3	3,299.9	4,031.0	5,109.4	6,394.2	7,947.7

Table 5.6. Share of energy consumptions in the electricity sector by resources in the BASE scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	36.1	51.7	40.7	63.9	71.4	79.8	85.7	89.1	91.2
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.7	0.6	0.5	0.4	0.4	0.3	0.2	0.1	0.1
HEAVY FUEL OIL	3.0	0.3	0.6	5.3	0.3	0.3	0.0	0.0	0.0	0.0
HYDRO	16.5	13.1	12.4	9.8	7.0	5.5	4.1	2.8	2.0	1.6
NATURAL GAS	37.2	48.1	29.7	39.3	25.3	19.6	13.7	10.7	8.5	7.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	4.4	4.0	3.0	2.6	2.1	0.5	0.2	0.1
TOTAL PERCENTAGE	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The results of both scenarios display similar trends; the most important ones being the changes in fuel consumptions in all sectors. Especially a significant rise is observed in consumption of hydro (compared to the BAUSOLF scenario) and coal (the highest increase being in coal consumption in both scenarios: since it is the cheapest option, both mostly prefer to use coal to generate electricity). Also, natural gas consumption (which is one of the less emitting energy carriers) is increased. These trends strongly affect the CO<sub>2</sub> emissions and costs results. On the other hand, the profile of wind energy is noteworthy. Since installed power is updated in the BASE scenario, a significant difference of wind energy consumption is observed between the BAUSOLF and the BASE scenarios. Coal

consumption is increasing over the planning horizon, since it is the cheapest option, the model mostly prefers to use coal to generate electricity.

Besides, when the BASE scenario is compared to the previous model's BAUSOLF scenario, the similarity between results can be considered as a validation of the new model.

## **5.2. Alternative Scenarios**

In order to examine the effects of various policy alternatives through the energy model, different "What-if" scenarios are developed by including additional constraints to the model or/and changing some key parameters (such as prices). These additional scenarios which are different from the base scenario are called alternative scenarios. For instance, in the base scenario, there is no constraint that forces or encourages the model to reduce CO<sub>2</sub> emission levels. Therefore, some scenarios are prepared to investigate the impacts of policy alternatives enforcing lesser CO<sub>2</sub> emissions.

In the following subsections, different alternative scenarios are described and then their results are analyzed and compared with the reference scenario.

### **5.2.1. The Emission Restriction Scenarios**

Turkey, as a fast developing country, takes some precautions for her future of energy sector and aims to combat climate change. Although, she has not committed herself to specific quantities in reducing GHG emissions, she is aiming at reducing CO<sub>2</sub> emissions as much as possible. Therefore, in this group of scenarios, overall CO<sub>2</sub> emissions are restricted by 20% and 40% in order to analyze the effects of strict limits in reducing overall CO<sub>2</sub> emissions.

In the 20% emission restriction scenario, which is named the RS\_C\_20 scenario, a constraint set is added to the base scenario in order to reduce the CO<sub>2</sub> emission level of energy sector by 20% (compared to the CO<sub>2</sub> emissions in the BASE scenario) in all periods. This is accomplished by adding an upper bound (which is 80% of the base scenario's periodic CO<sub>2</sub> level) to each period. However, as 2006 and 2011 are over, the

CO<sub>2</sub> emissions are actually bounded from 2016 onwards in this emission reduction scenario.

In the 40% emission restriction scenario, which is named the RS\_C\_40 scenario, a constraint set is added to the base scenario in order to reduce the CO<sub>2</sub> emission level of energy sector by 40% (compared to the CO<sub>2</sub> emissions in the BASE scenario) in all periods. This is accomplished by adding an upper bound (which is 60% of the base scenario's periodic CO<sub>2</sub> level) to each period. The remaining of the model is not altered and again, emission bounds are not applied to 2006 and 2011 periods. Table 5.7 shows the overall CO<sub>2</sub> emission bounds for both scenarios.

Table 5.7. The CO<sub>2</sub> emission bounds for the RS\_C\_20 and the RS\_C\_40 scenarios (kt).

	2016	2021	2026	2031	2036	2041	2046	2051
<b>RS_C_20</b>	348,596	444,209	577,178	721,495	911,196	1,161,792	1,504,994	1,931,469
<b>RS_C_40</b>	261,447	333,157	432,884	541,121	683,397	871,344	1,128,745	1,448,602

For the RS\_C\_20 scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.8 and 5.9, respectively.

Table 5.8. Energy consumptions of the electricity sector by resources in the RS\_C\_20 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
<b>BIO ENERGY</b>	0.0	2.4	6.1	6.0	2.1	0.9	0.0	0.0	0.0	0.0
<b>COAL</b>	571.3	536.1	513.1	470.8	1,172.8	1,875.0	2,669.9	3,636.8	4,644.9	6,308.4
<b>DIESEL</b>	4.6	4.7	0.9	0.9	0.7	0.5	0.1	0.1	0.1	0.1
<b>GEOHERMAL</b>	1.3	10.1	10.5	10.9	11.3	11.7	10.4	9.2	7.9	6.6
<b>HEAVY FUEL OIL</b>	38.4	5.4	6.1	5.8	4.3	11.0	0.4	0.3	0.3	0.3
<b>HYDRO</b>	218.5	218.6	333.9	334.0	333.9	334.0	333.7	326.0	325.5	294.5
<b>NATURAL GAS</b>	492.8	735.0	515.2	841.7	763.5	778.7	728.7	764.3	982.9	1,123.5
<b>SOLAR</b>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>WIND</b>	0.0	18.7	72.0	92.1	94.4	125.5	142.1	155.1	168.1	175.1
<b>ANNUAL TOTAL</b>	1,326.9	1,530.9	1,457.8	1,762.1	2,383.0	3,137.1	3,885.3	4,891.6	6,129.7	7,908.6

Table 5.9. Share of energy consumptions in the electricity sector by resources in the RS\_C\_20 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
<b>BIO ENERGY</b>	0.0	0.2	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0
<b>COAL</b>	43.1	35.0	35.2	26.7	49.2	59.8	68.7	74.3	75.8	79.8
<b>DIESEL</b>	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
<b>GEOTHERMAL</b>	0.1	0.7	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1
<b>HEAVY FUEL OIL</b>	2.9	0.4	0.4	0.3	0.2	0.4	0.0	0.0	0.0	0.0
<b>HYDRO</b>	16.5	14.3	22.9	19.0	14.0	10.6	8.6	6.7	5.3	3.7
<b>NATURAL GAS</b>	37.1	48.0	35.3	47.8	32.0	24.8	18.8	15.6	16.0	14.2
<b>SOLAR</b>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>WIND</b>	0.0	1.2	4.9	5.2	4.0	4.0	3.7	3.2	2.7	2.2
<b>TOTAL PERCENTAGE</b>	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

According to these scenario results, coal is still the most dominant primary energy source of the electricity generation sector in Turkey and its usage almost doubles at the end of the planning horizon, because it is the least cost alternative. Nevertheless, the coal usage in the RS\_C\_20 scenario is lower than that of the base scenario. Since coal-fired power plants are major sources of CO<sub>2</sub> emissions, the model prefers to use other energy sources such as hydro, wind, natural gas, etc. which emit less CO<sub>2</sub>, in order to decrease the level of coal based CO<sub>2</sub> emission. The consumption of another pollutant, heavy fuel oil has also decreased and natural gas has increased compared to the base scenario. On the other hand, it must be mentioned that, hydro and natural gas shares drop over time (hydro because of its limited resource, natural gas because of its cost).

Hydro power usage in the RS\_C\_20 scenario is 2% greater than that of the base scenario at the end of the planning horizon. Especially, medium scaled privately owned hydro power plants have the largest share of hydro power plants. Moreover, wind based electricity generation is increasing. On the other hand, solar usage is not different from that of the base scenario.

For the RS\_C\_40 scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.10 and 5.11, respectively.

Table 5.10. Energy consumptions of the electricity sector by resources in the RS\_C\_40 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.8	6.0	2.6	0.9	0.0	0.0	0.0	0.0
COAL	571.3	348.1	0.0	22.0	752.0	1,510.6	2,613.7	3,956.8	5,288.4	7,368.2
DIESEL	4.6	3.9	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1
GEO THERMAL	1.3	10.1	10.5	10.9	11.3	11.7	10.4	9.2	7.9	6.6
HEAVY FUEL OIL	38.4	0.8	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	532.0	532.4	532.2	531.6	506.7	498.5	492.4	451.3
NATURAL GAS	492.8	735.0	373.6	735.0	633.3	639.3	515.3	539.3	650.1	672.5
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	141.9	185.2	187.6	218.7	235.3	178.4	168.1	184.7
ANNUAL TOTAL	1,326.9	1,337.5	1,063.7	1,491.4	2,118.9	2,912.7	3,881.8	5,182.1	6,607.0	8,683.4

Table 5.11. Share of energy consumptions in the electricity sector by resources in RS\_C\_40 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.5	0.4	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.1	26.0	0.0	1.5	35.5	51.9	67.3	76.4	80.0	84.9
DIESEL	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GEO THERMAL	0.1	0.8	1.0	0.7	0.5	0.4	0.3	0.2	0.1	0.1
HEAVY FUEL OIL	2.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	16.3	50.0	35.7	25.1	18.3	13.1	9.6	7.5	5.2
NATURAL GAS	37.1	55.0	35.1	49.3	29.9	21.9	13.3	10.4	9.8	7.7
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.4	13.3	12.4	8.9	7.5	6.1	3.4	2.5	2.1
TOTAL PERCENTAGE	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

When the energy consumptions in the RS\_C\_40 scenario are compared with those in the RS\_C\_20 scenario, it is observed that coal consumption has increased (even though emission restriction is higher). The main reason of this phenomenon is the adoption of new CCS technologies that provide for coal consumption, while capturing GHG emissions and thus leading to the emission of less CO<sub>2</sub>. Especially, CCS technology (for instance nearshore carbon capture pipeline technology) usage is increasing beyond 2036 which is period that coal consumption gets greater in the RS\_C\_40 scenario than that of the RS\_C\_20 scenario. Also, it is worth mentioning that, the total fuel consumption in the RS\_C\_20 scenario is nearly the same as that of the RS\_C\_40 scenario.

Since CO<sub>2</sub> emissions are bounded, the consumption of renewable energy resources such as hydro and wind are preferred as clean alternatives.

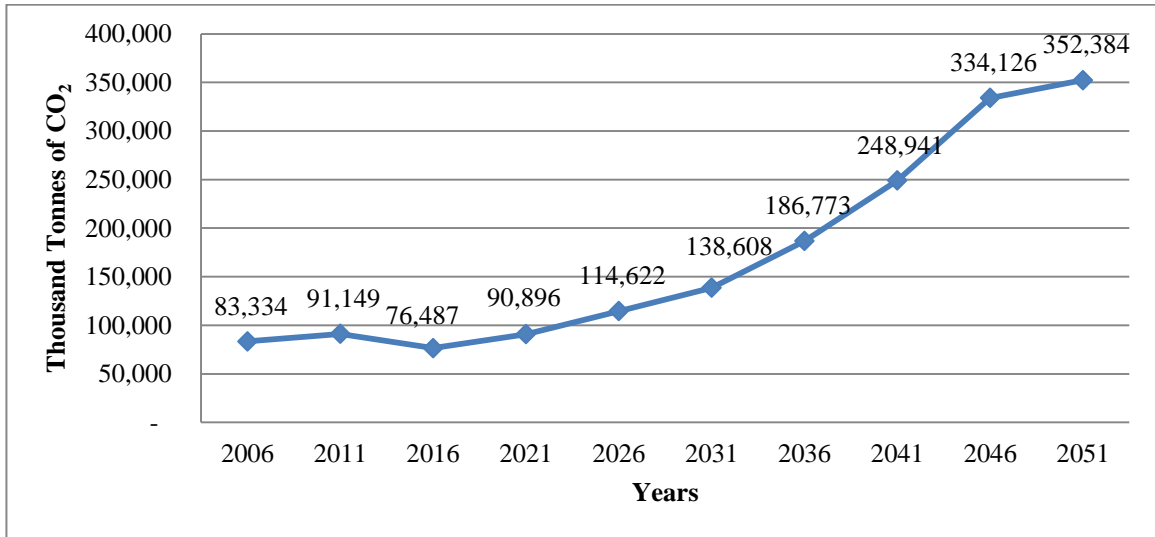


Figure 5.6. CO<sub>2</sub> Emissions of the electricity sector in the RS\_C\_20 scenario.

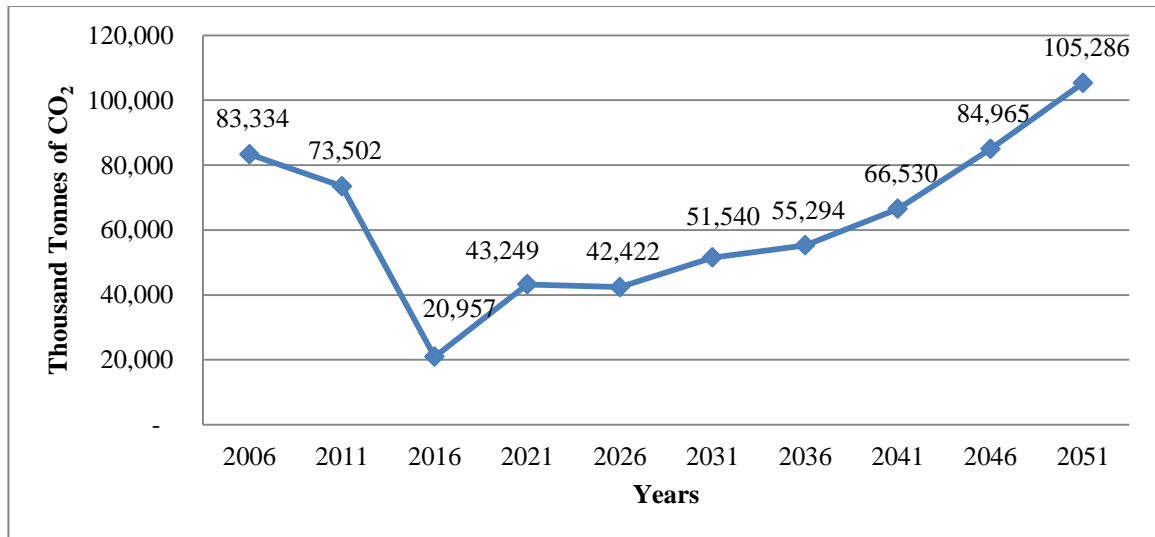


Figure 5.7. CO<sub>2</sub> Emissions of the electricity sector in the RS\_C\_40 scenario.

The level of CO<sub>2</sub> emissions in both the RS\_C\_40 and RS\_C\_20 scenarios show sharp reductions because the 20% and 40% emission reduction constraints are applied from 2016 onwards. However, CO<sub>2</sub> emissions in these scenarios still have an increasing trend in time.

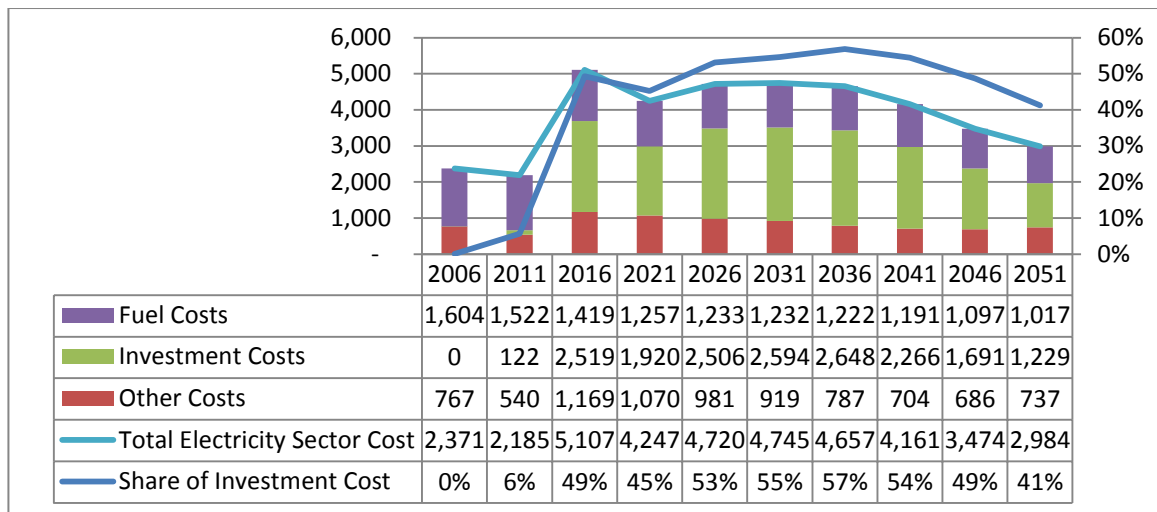


Figure 5.8. Costs of the electricity sector in the RS\_C\_20 scenario (M pounds).

Figure 5.8 shows the cost behavior in the RS\_C\_20 Scenario. As it can be inferred from this figure, the fuel cost is decreasing period by period. Also, especially in 2016 and following periods, there is an increase in the level of investment cost. The reason of these cost increases is the bound on CO<sub>2</sub> emissions. The model cannot satisfy the emissions constraints with conventional technologies; therefore, it invests in new and less polluting technologies that have higher investment costs but lesser fuel costs. Moreover, as it can be seen from Figure 5.8, the share of investment cost is more than half of the total cost at the end of the planning horizon. When the costs in this scenario are compared to those in the base scenario, investment costs are higher from 2016 onwards, also towards the end of the planning horizon fuel costs become lower.

The cost peaks in certain periods can be explained as overlapping of replacement time of many technologies because the installation of these technologies occurs at the same period and then results in high investment costs.

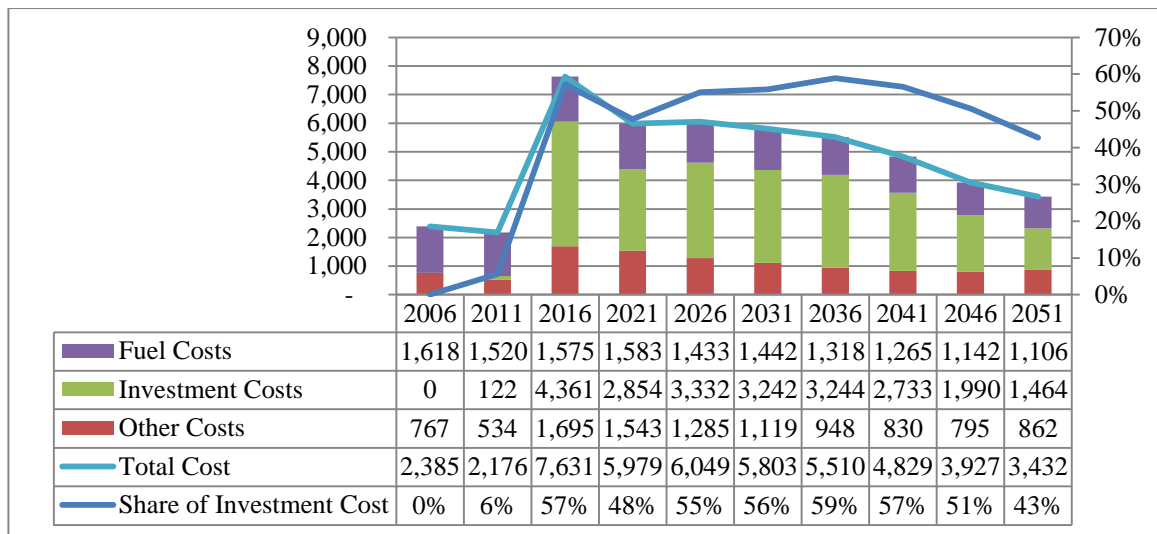


Figure 5.9. Costs of the electricity sector in the RS\_C\_40 scenario (M pounds).

When the costs in the RS\_C\_40 scenario are compared with those in the RS\_C\_20 scenario, it is observed that the investment costs are even higher in the RS\_C\_40 scenario. Since emission restrictions are higher in the RS\_C\_40 scenario, the model chooses to invest more in new and less emitting technologies like CCS plants. As CO<sub>2</sub> emissions are restricted, the model invests more in CCS technologies (for instance, near-shore carbon capture pipeline for coal based technologies).

### 5.2.2. The Nuclear Scenarios

When the results of the base scenario are analyzed, it can be seen that, the model does not prefer to invest in nuclear power plants over the planning horizon. Therefore, some alternative scenarios regarding nuclear power generation are generated.

In the fast nuclear scenario, namely the RS\_NUCF scenario, a constraint on electricity generation, which forces nuclear power generation to be at least a certain percentage of total available electricity generation is included. The minimum share of nuclear power generation in total electricity production activity in 2016 is 6% and the shares for each period are as follows: 12% by 2021, 15% by 2026, 18% by 2031, 21% by 2036, 24% by 2041, 27% by 2046 and 30% by 2051. Geothermal capacity (for both electricity and heat generation) is also increased by 50% in this scenario.



Table 5.14. Energy consumptions of the electricity sector by resources in the RS\_NUCS scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	6.1	5.1	1.6	0.9	0.0	0.0	0.0	0.0
COAL	571.3	536.7	809.8	804.5	1,555.2	2,190.6	2,987.5	4,074.9	5,396.2	6,952.2
DIESEL	3.7	4.7	1.5	1.5	1.1	0.6	0.1	0.1	0.1	0.1
GEOTHERMAL	1.3	10.1	10.5	10.9	11.3	11.7	10.4	9.2	7.2	6.1
HEAVY FUEL OIL	39.3	4.1	9.9	107.3	7.1	11.8	0.7	0.7	0.7	0.3
HYDRO	218.5	200.4	200.4	200.4	182.3	181.9	166.3	145.5	130.7	125.4
NATURAL GAS	493.8	735.0	491.5	765.5	653.4	639.8	567.4	539.8	536.0	553.9
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	43.4	54.0	50.3	58.6	54.9	26.3	10.9	10.9
NUCLEAR	0.0	0.0	89.8	174.7	251.3	327.8	404.4	460.8	465.6	438.9
ANNUAL TOTAL	1,328.0	1,512.0	1,662.9	2,123.9	2,713.5	3,423.7	4,191.7	5,257.4	6,547.5	8,087.7

Table 5.15. Share of energy consumptions in the electricity sector by resources in the RS\_NUCS scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	35.5	48.7	37.9	57.3	64.0	71.3	77.5	82.4	86.0
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.7	0.6	0.5	0.4	0.3	0.2	0.2	0.1	0.1
HEAVY FUEL OIL	3.0	0.3	0.6	5.1	0.3	0.3	0.0	0.0	0.0	0.0
HYDRO	16.5	13.3	12.0	9.4	6.7	5.3	4.0	2.8	2.0	1.6
NATURAL GAS	37.2	48.6	29.6	36.0	24.1	18.7	13.5	10.3	8.2	6.8
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	2.6	2.5	1.9	1.7	1.3	0.5	0.2	0.1
NUCLEAR	0.0	0.0	5.4	8.2	9.3	9.6	9.6	8.8	7.1	5.4
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

After 2016, when nuclear power generation is utilized, bio energy consumption decreases in the RS\_NUCF scenario and remains the same in the RS\_NUCS scenario, compared to that in the base scenario. Whereas share of coal is 91.2% in 2051 in the base scenario, the coal share decreases to 49.6% at the same period in the RS\_NUCF scenario. The model prefers to satisfy energy demand by nuclear power plants so it needs less coal.

Natural gas consumption in the slow nuclear scenarios is lesser than that of the base scenario. Because natural gas and coal are the leading fuels in the electricity sector of Turkey, the usage of nuclear power mostly affects the consumptions of these resources rather than the renewables (bio energy, geothermal, hydro, and solar). Increase in the consumption of wind energy in the RS\_NUCS scenario is noteworthy. However, wind

energy consumptions in the nuclear scenarios are lower than those in the emission restriction scenarios.

Since the nuclear power is relatively costly; if the model is not forced to use nuclear power energy by constraints, it does not prefer investing in nuclear energy. When the results of nuclear scenarios are compared to those in the emission restriction scenarios, hydro consumption is lower in the nuclear scenarios. Also, coal consumptions in the emission restriction scenarios are higher than those in the nuclear scenarios towards the end of the planning horizon.

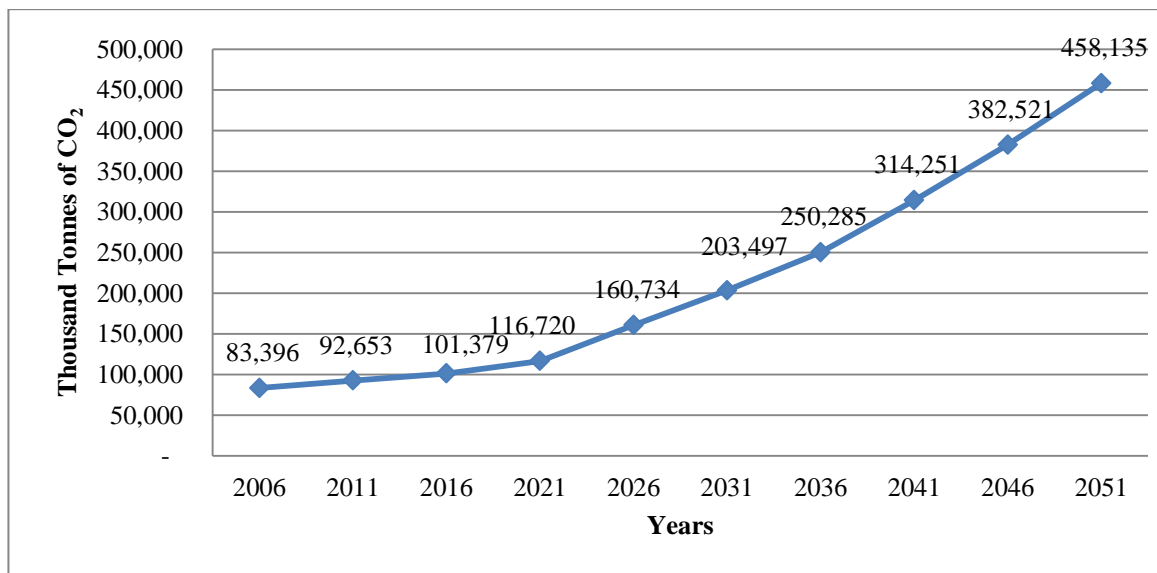


Figure 5.10. CO<sub>2</sub> Emissions of the electricity sector in the RS\_NUCF scenario.

Since coal is the least costly alternative among fossil fuels, its share increases each period even in the RS\_NUCF scenario. Thus, CO<sub>2</sub> emissions are still increasing period by period. However, the level of CO<sub>2</sub> emissions is lower than the base scenario, since some fossil fuels (including coal) are replaced by nuclear power.

Also, CO<sub>2</sub> emissions in the slow nuclear scenario are lower than those in the base scenario. However, the decrease in the emission level in the RS\_NUCS scenario is not as much as that in the RS\_NUCF scenario, primarily because of the difference between nuclear energy consumption rate of these two scenarios.

CO<sub>2</sub> emissions in the nuclear scenarios are lower than those in the base scenario. However, these emissions are not as low as those in the emission restriction scenarios.

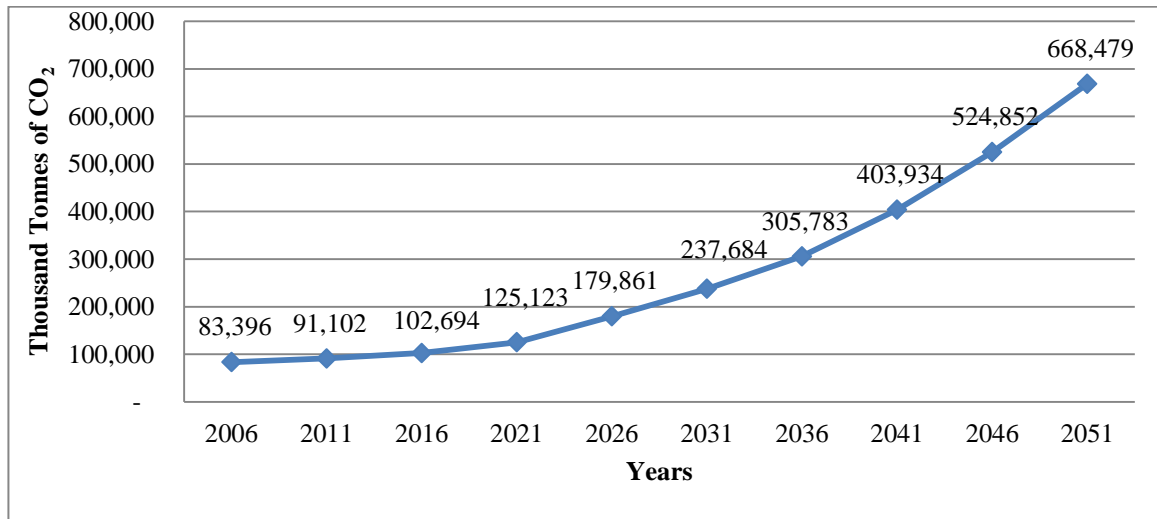


Figure 5.11. CO<sub>2</sub> Emissions of the electricity sector in the RS\_NUCS scenario.

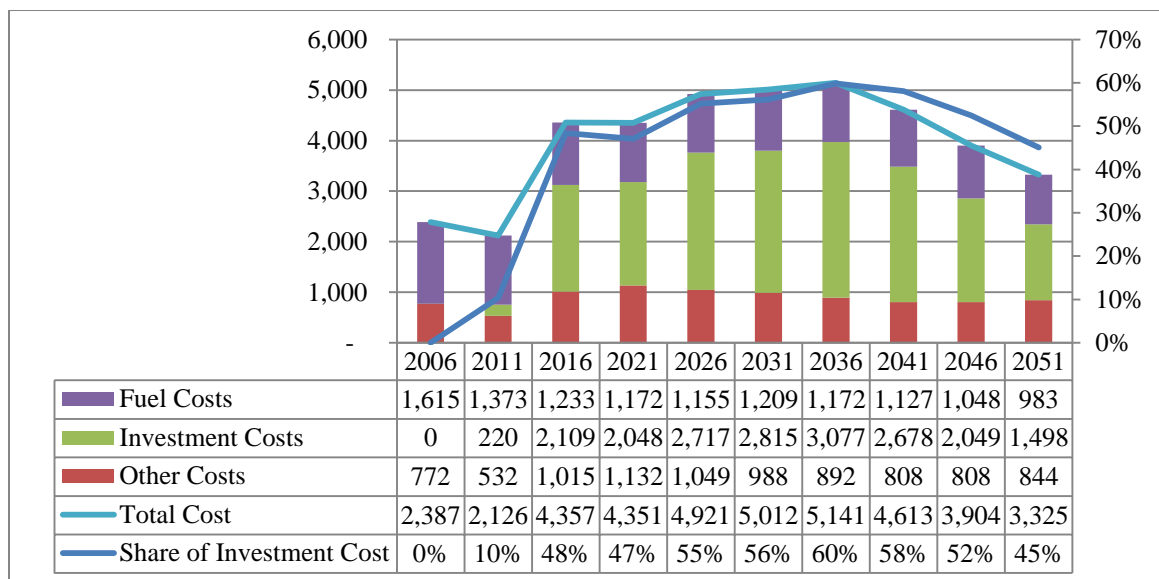


Figure 5.12. Costs of the electricity sector in the RS\_NUCF scenario (M pounds).

Because of the enforced utilization of the relatively more costly nuclear power generation, there is a significant increase in the level of investment cost in this scenario. On the other hand, the shift from coal usage to nuclear power usage results in lesser fuel costs. So, the fuel cost of electricity generation sector decreases in the RS\_NUCF scenario.

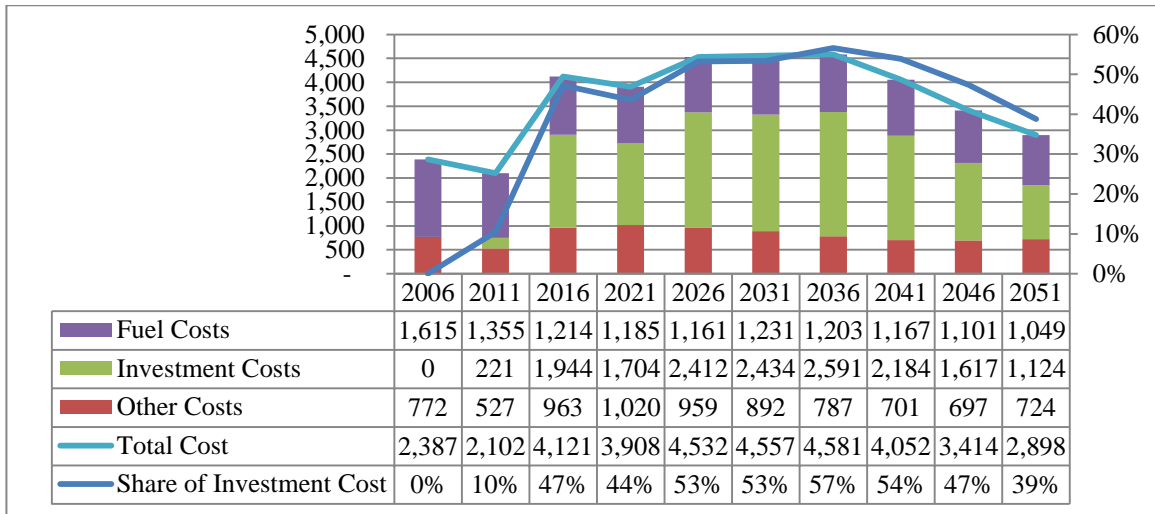


Figure 5.13. Costs of the electricity sector in the RS\_NUCS scenario (M pounds).

When the RS\_NUCS scenario is compared with the RS\_NUCF scenario, the difference in investment costs and fuel costs are noticeable. As can be inferred from Figures 5.12 and 5.13, as the nuclear energy share increases and coal share decreases, the investment costs increase and fuel cost decrease.

When the cost results of nuclear scenario are compared to those in the base and the emission restriction scenarios, investment costs of the nuclear scenarios are higher than those in the base scenario. The investment costs of the RS\_C\_40 scenario are slightly higher than those in the RS\_NUCF scenario. Also, the investment costs of the RS\_C\_20 scenario are slightly higher than those in the RS\_NUCS scenario. Fuel costs of the RS\_NUCF scenario is the lowest among those of the nuclear and emission restriction scenarios. Furthermore, total costs of the RS\_C\_40 scenario are highest among those of the nuclear and emission restriction scenarios. These results show that reducing emissions 40% is more costly than nuclear power usage.

### 5.2.3. The CCS Scenarios

In these scenarios, the model is forced to employ CCS technologies. In the high CCS scenario, which is named the RS\_CCSH scenario, there is a constraint that forces CCS technology to be deployed in at least a certain percentage of coal-based electricity



Table 5.18. Energy consumptions of the electricity sector by resources in the RS\_CCSH scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	3.7	4.2	1.6	0.9	0.0	0.0	0.0	0.0
COAL	571.3	553.2	1,040.5	1,035.2	1,784.4	2,479.0	3,294.1	4,376.4	5,564.2	7,018.6
DIESEL	3.7	4.7	1.5	1.5	1.1	0.6	0.1	0.1	0.1	0.1
GEOTHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.1
HEAVY FUEL OIL	39.3	4.6	9.9	82.2	7.1	8.6	0.7	0.7	0.7	0.3
HYDRO	218.5	200.4	200.4	200.4	182.3	182.4	171.4	158.6	154.4	144.0
NATURAL GAS	493.8	735.0	428.6	741.8	663.7	656.7	606.7	657.6	805.0	978.8
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	43.4	54.0	50.3	58.6	55.5	27.5	13.7	12.5
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TOTAL	1,328.0	1,529.0	1,743.7	2,135.6	2,707.3	3,404.2	4,144.1	5,234.5	6,549.8	8,163.4

Table 5.19. Share of energy consumptions in the electricity sector by resources in the RS\_CCSH scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	36.2	59.7	48.5	65.9	72.8	79.5	83.6	85.0	86.0
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.7	0.9	0.8	0.6	0.5	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	3.0	0.3	0.6	3.9	0.3	0.3	0.0	0.0	0.0	0.0
HYDRO	16.5	13.1	11.5	9.4	6.7	5.4	4.1	3.0	2.4	1.8
NATURAL GAS	37.2	48.1	24.6	34.7	24.5	19.3	14.6	12.6	12.3	12.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	2.5	2.5	1.9	1.7	1.3	0.5	0.2	0.2
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

As can be inferred from Table 5.16, the consumption of bio energy, diesel, geothermal, heavy fuel oil, hydro, solar and nuclear energy in the slow CCS scenario hardly differ from the base scenario. However, coal consumption is higher than that of the base scenario (until 2041) and becomes lower (about 3%) than that of the base scenario at the end of the planning horizon although it has an increasing trend over the planning horizon. This is because, CCS technology usage provides coal based electricity generation with less CO<sub>2</sub> emissions. Besides, wind energy consumption in the RS\_CCSL is lower than that of the base scenario until 2041. Natural gas consumption is lower than that of the base scenario until 2036 (about 1% in each period) and then it becomes higher.

The consumption of natural gas in the RS\_CCSH scenario is higher than that of the RS\_CCSL and base scenario. Also, coal consumption is higher than that of the RS\_CCSL and base scenarios until the period 2031, however after 2036 coal consumption is reduced. On the other hand, wind energy consumption is almost the same in the RS\_CCSH and RS\_CCSL scenarios. Natural gas consumption in the RS\_CCSH scenarios is higher than (about 5%) that of the RS\_CCSL scenario.

When the coal consumption in the CCS scenarios are compared to those in the nuclear scenarios, it can be seen that coal consumption in the CCS scenarios are higher than those in the nuclear scenarios. While, the gap between the coal consumption in the CCS scenarios and the RS\_NUCS scenario is very low, it gets larger between the CCS scenarios and the RS\_NUCF scenario. Natural gas consumption in the CCS scenarios is lower than that of the RS\_NUCS scenario and wind energy consumptions in the nuclear scenarios are almost the same as those in the CCS scenarios.

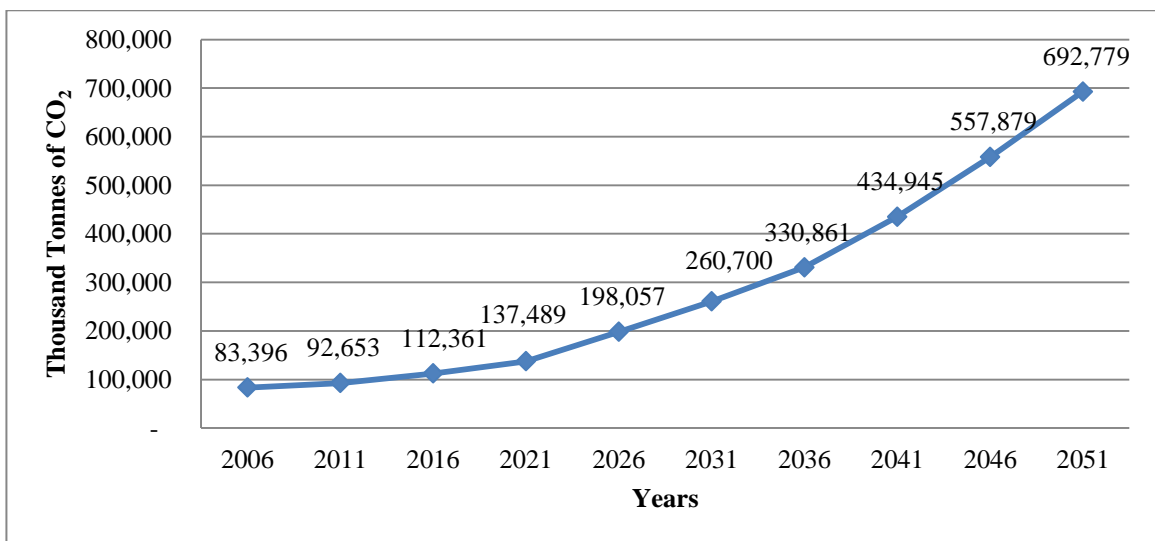


Figure 5.14. CO<sub>2</sub> Emissions of the electricity sector in the RS\_CCSL scenario.

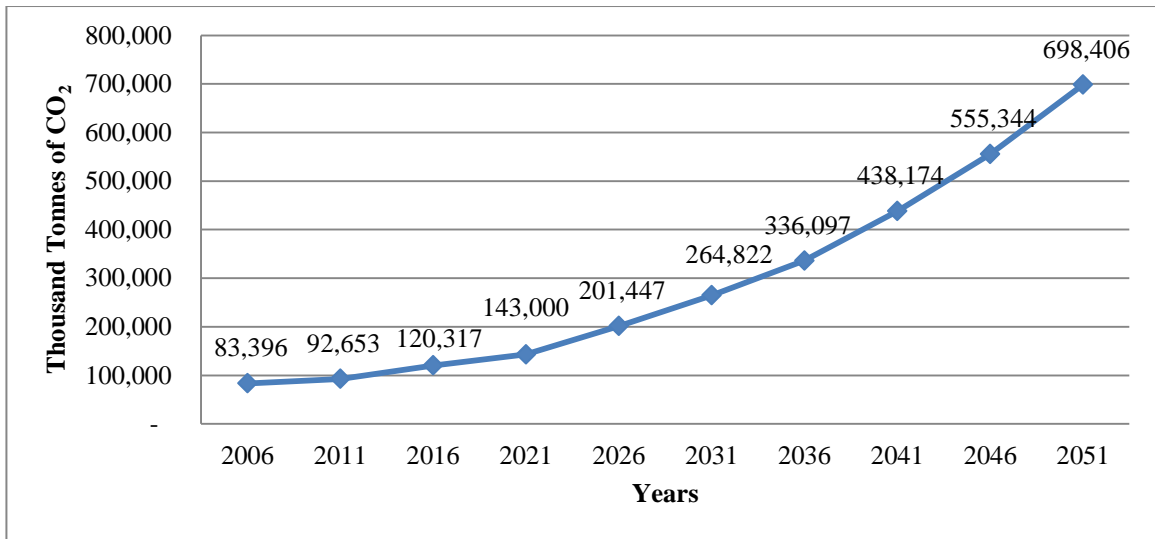


Figure 5.15. CO<sub>2</sub> Emissions of the electricity sector in the RS\_CCSH scenario.

With regard to energy consumption and CO<sub>2</sub> emissions, the “RS\_CCSH” and “RS\_CCSL” scenarios are very similar. It must be mentioned that total electricity sector CO<sub>2</sub> emissions in the RS\_CCSH and RS\_CCSL scenarios are higher than those in the base and nuclear scenarios. However, electricity sector CO<sub>2</sub> emissions in the emission restriction scenarios are the lowest compared to those in the nuclear and CCS scenarios.

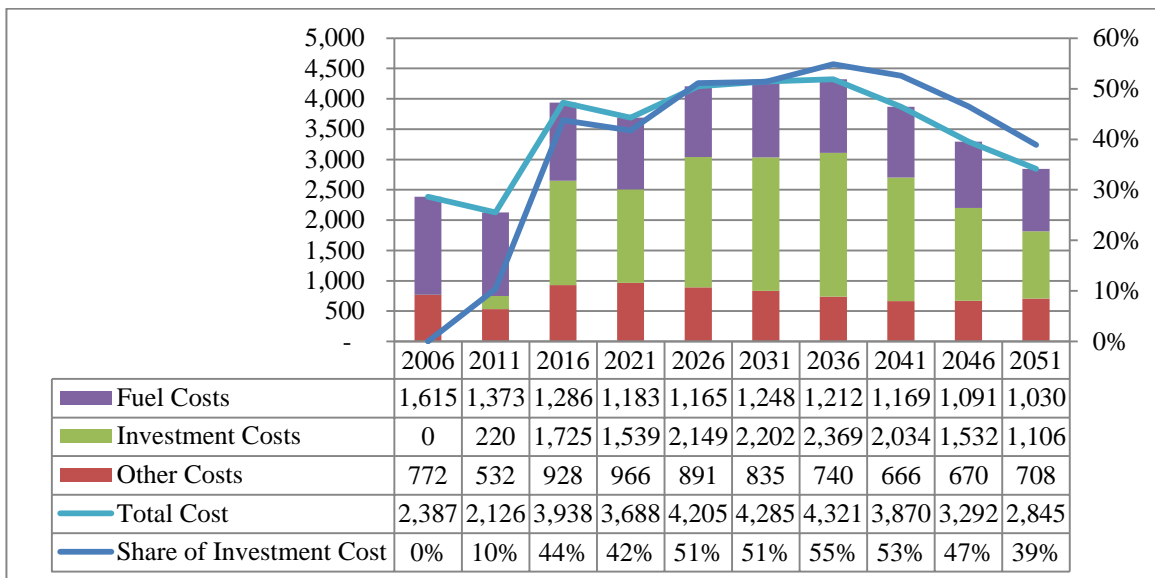


Figure 5.16. Costs of the electricity sector in the RS\_CCSH scenario (M pounds).

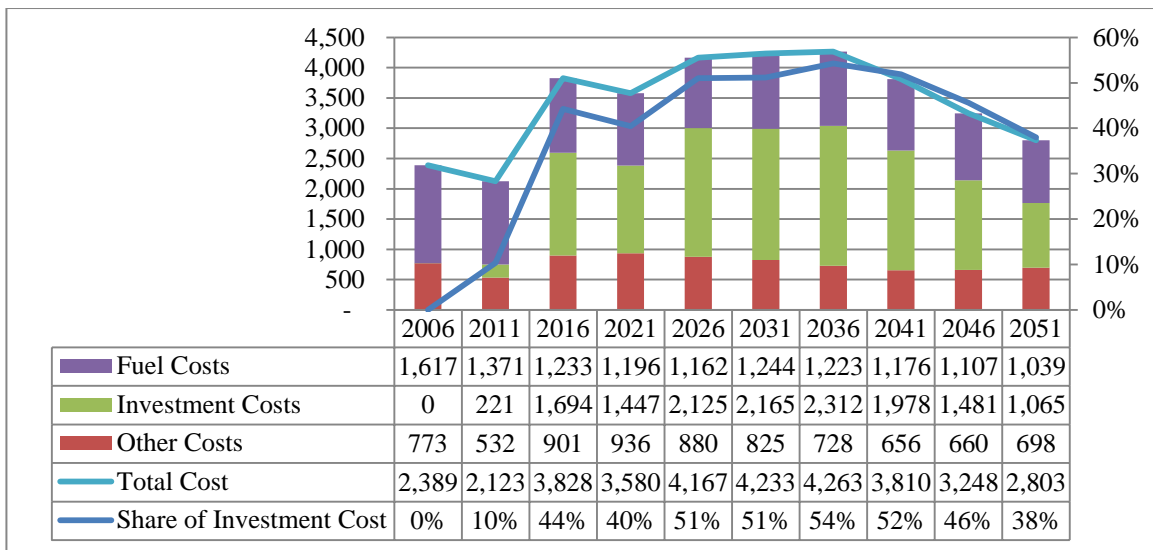


Figure 5.17. Costs of the electricity sector in the RS\_CCSL scenario (M pounds).

As shown in Figures 5.16 and 5.17, there is a sharp increase in the investment costs of the electricity sector (for both CCS scenarios) in 2016 (which is the period when CCS employment is started). On the other hand, the fuel costs and total cost of the electricity sector have decreasing trends (even though this decline is not very much) because coal consumption is increasing over the planning horizon, and it is the cheapest alternative). When total cost of the electricity sector is analyzed, it can be inferred that costs are higher in the periods when new technologies are installed or current technologies are replaced.

The fuel costs of the CCS scenarios are higher than those in the RS\_NUCF scenario, at the end of the planning horizon. Investment costs of the CCS scenarios are lower than those in the emission restriction scenarios and the nuclear scenarios (since nuclear power installation and new investments to reduce CO<sub>2</sub> are more costly than investment cost of CCS technologies). Furthermore, total costs of the CCS scenarios are lower than those in the nuclear scenarios and the emission restriction scenarios. Regarding fuel costs and total cost, the RS\_CCSL scenario is better than the RS\_CCSH scenario towards the end of the planning horizon.

#### 5.2.4. The Tax Scenarios

In this set of scenarios, penalties per ton of CO<sub>2</sub> emissions are applied to encourage CO<sub>2</sub> emissions reductions. Since there is a tax per ton of CO<sub>2</sub>, the model may prefer to reduce CO<sub>2</sub> emission through deployment of more costly but less CO<sub>2</sub> emitting technologies, in order to incur lesser penalties. It should be noted that in the tax scenarios, the model is not directly forced to reduce the amount of CO<sub>2</sub> emission at all times.

In this group of scenarios three levels of tax are evaluated (10 TL, 20 TL and 40 TL tax per tonne of CO<sub>2</sub> emissions). In the RS\_TAX10 scenario, 10 TL tax per tonne of CO<sub>2</sub> emissions is applied; in the RS\_TAX20 scenario, 20 TL tax per tonne of CO<sub>2</sub> emissions is applied; and in the RS\_TAX40 scenario, 40 TL tax per tonne of CO<sub>2</sub> emissions is applied. For the RS\_TAX10, RS\_TAX20, and RS\_TAX40 scenarios, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.20, 5.21, 5.22, 5.23, 5.24 and 5.25, respectively.

Table 5.20. Energy consumptions of the electricity sector by resources in the RS\_TAX10 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	6.1	5.1	1.6	0.9	0.0	0.0	0.0	0.0
COAL	571.3	536.1	804.0	798.7	1,566.1	2,220.2	3,001.3	4,114.1	5,246.4	6,648.9
DIESEL	3.7	4.5	1.5	1.5	1.1	0.7	0.1	0.1	0.1	0.1
GEOTHERMAL	1.3	10.1	10.5	10.9	11.3	11.7	10.4	9.2	7.9	6.1
HEAVY FUEL OIL	39.3	4.1	9.9	107.3	7.1	12.4	0.7	0.7	0.7	0.3
HYDRO	218.5	212.4	212.3	212.4	209.9	210.0	204.1	186.6	182.0	158.4
NATURAL GAS	493.8	735.0	481.3	778.7	666.7	672.2	622.2	659.2	805.6	978.8
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	72.0	92.1	88.4	106.4	103.3	46.7	23.4	21.4
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TOTAL	1,328.0	1,523.2	1,597.6	2,006.7	2,552.2	3,234.4	3,942.2	5,016.5	6,266.1	7,813.9



Table 5.24. Energy consumptions of the electricity sector by resources in the RS\_TAX40 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	6.1	5.1	1.6	0.9	0.0	0.0	0.0	0.0
COAL	571.3	536.1	722.8	717.5	1,411.1	2,128.8	2,892.1	3,809.4	4,923.3	6,215.8
DIESEL	3.7	4.6	1.3	1.3	0.9	0.5	0.1	0.1	0.1	0.1
GEOTHERMAL	1.3	10.1	10.5	10.9	11.3	11.7	10.4	9.2	7.9	6.6
HEAVY FUEL OIL	39.3	4.7	8.6	47.4	5.8	11.5	0.6	0.6	0.6	0.3
HYDRO	218.5	218.6	258.3	258.4	258.3	258.4	255.5	250.8	248.2	220.5
NATURAL GAS	493.8	735.0	457.5	755.2	727.5	735.8	685.8	764.5	926.5	1,180.1
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	72.0	108.6	110.9	142.0	158.6	171.6	149.0	156.1
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TOTAL	1,328.0	1,530.0	1,537.0	1,904.4	2,527.4	3,289.5	4,003.0	5,006.1	6,255.6	7,779.5

Table 5.25. Share of energy consumptions in the electricity sector by resources in the RS\_TAX40 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	35.0	47.0	37.7	55.8	64.7	72.2	76.1	78.7	79.9
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.7	0.7	0.6	0.4	0.4	0.3	0.2	0.1	0.1
HEAVY FUEL OIL	3.0	0.3	0.6	2.5	0.2	0.4	0.0	0.0	0.0	0.0
HYDRO	16.5	14.3	16.8	13.6	10.2	7.9	6.4	5.0	4.0	2.8
NATURAL GAS	37.2	48.0	29.8	39.7	28.8	22.4	17.1	15.3	14.8	15.2
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	4.7	5.7	4.4	4.3	4.0	3.4	2.4	2.0
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

One key observation in the tax scenarios is that nuclear energy is not preferred to generate electricity not only in the base scenario, but also in these scenarios. However, as the tax amount increases, coal consumption decreases, in the meantime hydro, natural gas and wind energy consumptions increase. Since coal is the greatest contributor to CO<sub>2</sub> emissions, the fuel consumption for electricity generation shifts from coal to hydro, natural gas and wind (which are clean energy alternatives). Besides, as it can be inferred from Tables 5.20, 5.21, 5.22, 5.23, 5.24 and 5.25 that when tax is applied on per ton of CO<sub>2</sub>, bio energy, diesel, geothermal, heavy fuel oil and solar energy consumptions remain nearly the same as those in the base scenario.

Coal consumptions in the emission restriction scenarios are lower than those in the tax scenarios, but coal consumptions in the CCS scenarios are higher than those in the tax scenarios. However, hydro power in the emission restriction scenarios are lower than those in the tax scenarios. Natural gas consumptions in the RS\_C\_20 scenario is higher than those in the tax scenarios, but natural gas consumptions in the RS\_C\_40 scenario is lower than those in the tax scenarios. Wind energy consumptions in the emission restriction scenarios are higher than those in the tax scenarios except for the RS\_TAX40 scenario.

Heavy fuel oil consumptions in the CCS scenarios are higher than those in the tax scenarios. Natural gas consumption in the RS\_CCSL scenario is lower than those in the tax scenarios. Hydro and wind energy consumptions in the CCS scenarios and nuclear scenarios are lower than those in the tax scenarios. On the other hand, geothermal and nuclear consumptions in the nuclear scenarios are higher than those in the tax scenarios because of the nuclear power enforcement and increased availability of the cheaper geothermal option in the nuclear scenarios. Coal consumptions in the nuclear scenarios are lower than those in the tax scenarios, which further underlines how large a shift away from coal nuclear energy brings about. Therefore, nuclear scenarios are more powerful than tax scenarios in terms of reducing coal consumption.

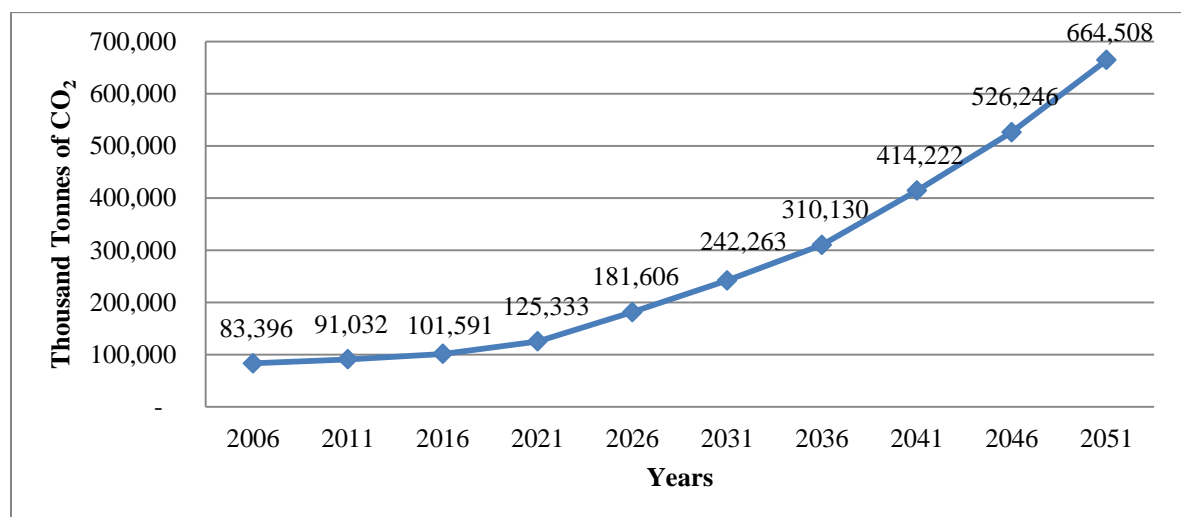


Figure 5.18. CO<sub>2</sub> Emissions of the electricity sector in the RS\_TAX10 scenario.

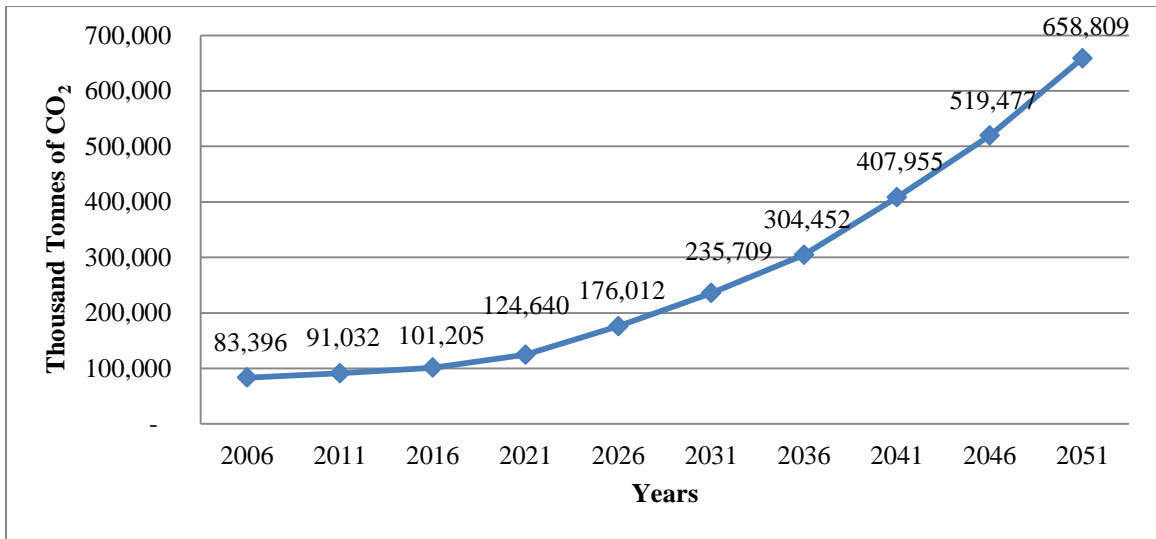


Figure 5.19. CO<sub>2</sub> Emissions of the electricity sector in the RS\_TAX20 scenario.

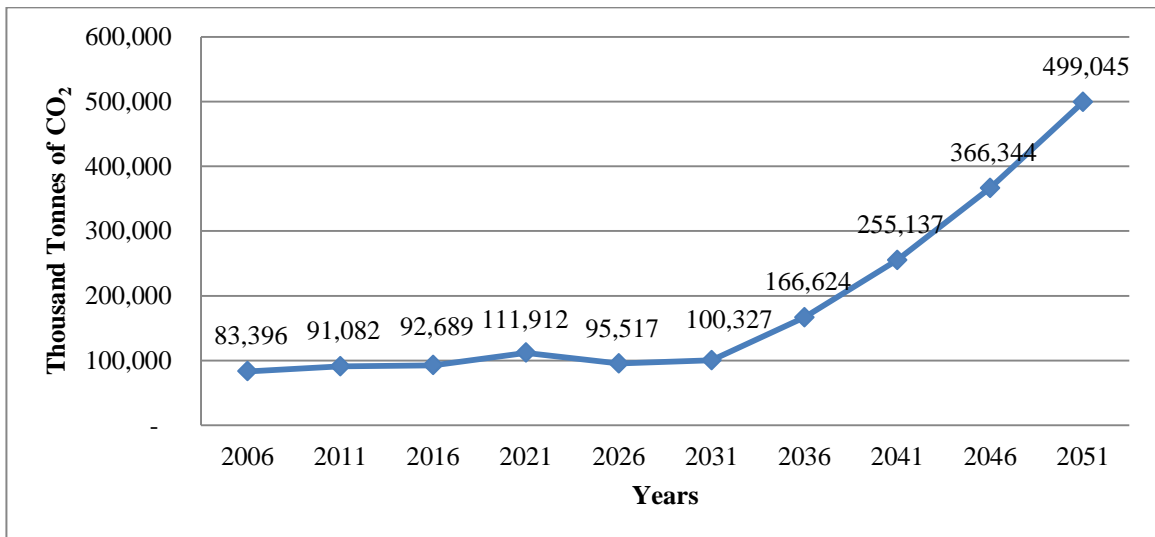


Figure 5.20. CO<sub>2</sub> Emissions of the electricity sector in the RS\_TAX40 scenario.

When Figures 5.18, 5.19 and 5.20 are analyzed, it can be seen that increasing tax amounts result in diminishing CO<sub>2</sub> emissions. The “RS\_TAX10” and “RS\_TAX20” scenarios are very similar in terms of CO<sub>2</sub> emissions because the decreasing rate of total electricity sector CO<sub>2</sub> emissions in the “RS\_TAX10” and “RS\_TAX20” scenarios compared to that of the base scenario are 4% and 6% (at the end of the planning horizon), respectively. However, the difference in the RS\_TAX40 scenario is more explicit because the decrease rate of total electricity sector CO<sub>2</sub> emissions in this scenario is 35% compared to that of the base scenario.

CO<sub>2</sub> emissions in the tax scenarios are higher than those in the emission restriction scenarios, but lower than those in the CCS scenarios. When these results are compared to those in the nuclear scenarios, it can be concluded that the emissions in the RS\_NUCF and RS\_C\_40 scenarios are very similar. Also the emissions in the RS\_NUCS and RS\_C\_20 scenarios are almost the same.

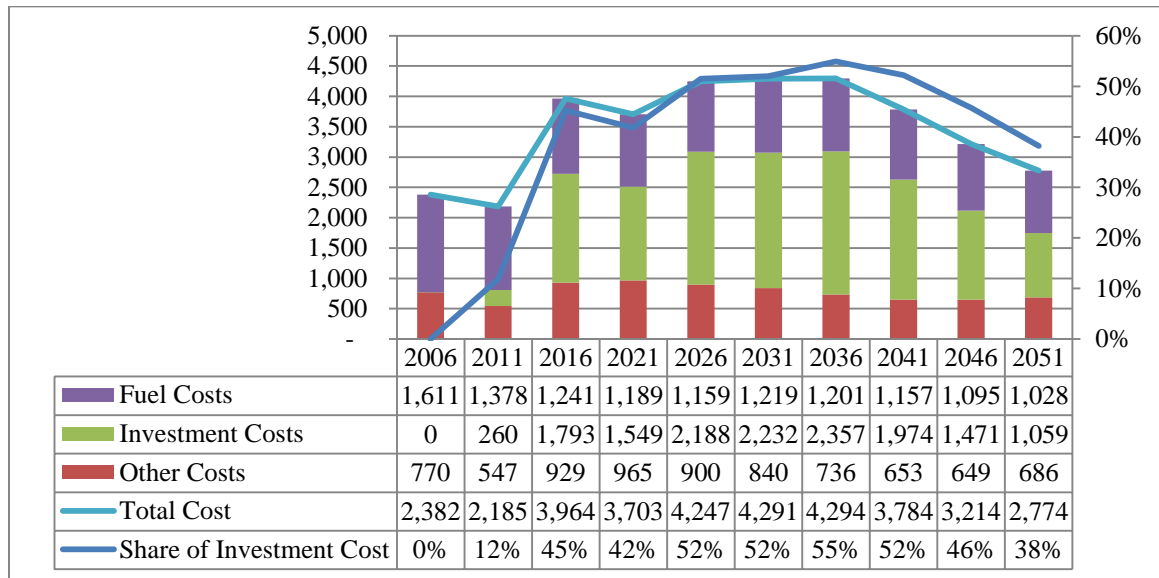


Figure 5.21. Costs of the electricity sector in the RS\_TAX10 scenario (M pounds).

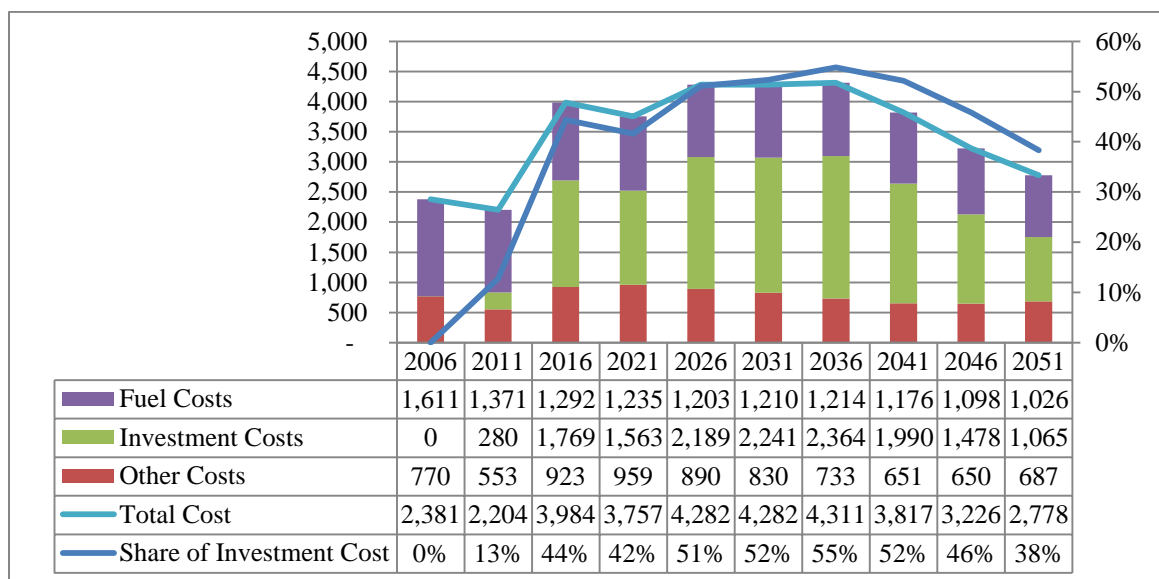


Figure 5.22. Costs of the electricity sector in the RS\_TAX20 scenario (M pounds).

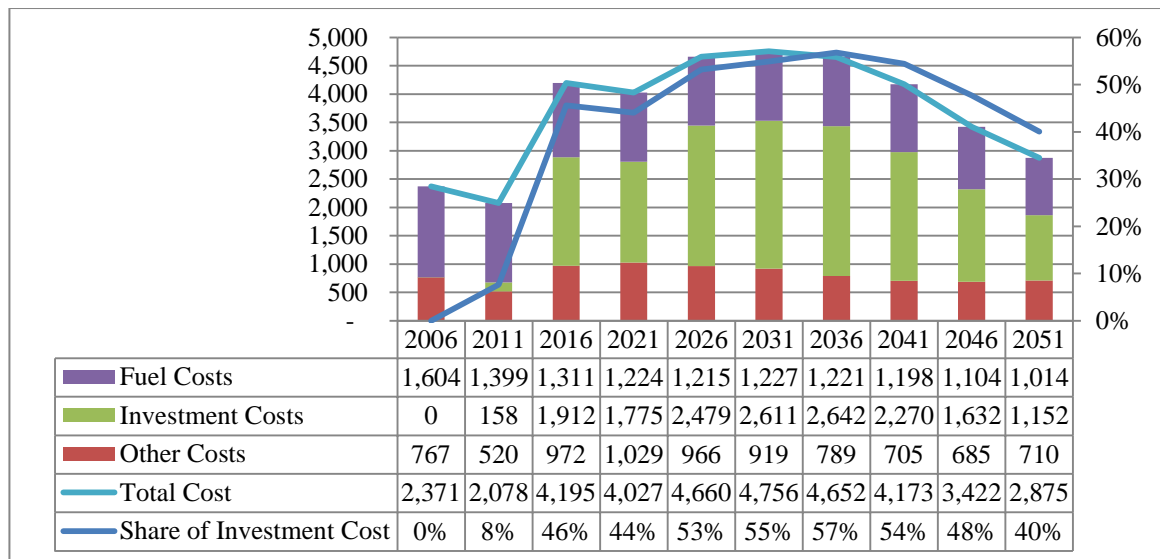


Figure 5.23. Costs of the electricity sector in the RS\_TAX40 scenario (M pounds).

The applied tax amount is not directly proportional to the total system cost. The underlying reason of this is that the MARKAL model does not treat taxes as costs (since producers or consumers pay the emission taxes to the governments which result in revenue in the model). So, the model is optimized under this assumption.

Table 5.26. The tax results for each period in tax scenarios.

Scenarios	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051	Total Tax	Electricity Sector Cost	Total System Cost
<b>BASE</b>	0	0	0	0	0	0	0	0	0	0	0	174,003	3,588,205
<b>RS_TAX10</b>	0	0	1,148	1,154	1,174	1,154	1,141	1,147	1,144	1,155	46,084	174,189	3,588,731
<b>RS_TAX20</b>	0	0	2,181	2,172	2,217	2,215	2,205	2,209	2,236	2,273	88,543	175,117	3,590,646
<b>RS_TAX40</b>	0	0	4,191	4,147	3,781	3,602	3,695	3,756	3,961	4,146	156,391	186,047	3,608,640

When the costs in the tax scenarios are compared to those in the base scenario, the cost differences are very slight. The total cost of the RS\_TAX10 scenario is slightly higher than that of the base scenario. Especially, the difference between costs of these scenarios is recognizable in investment costs because the investment costs of the RS\_TAX10 scenario are higher than those in the base scenario.

When the costs in the RS\_TAX20 scenario are compared to those in the RS\_TAX10 scenario, it can be seen that fuel costs in the RS\_TAX20 are higher than those in the RS\_TAX10 scenario. When the costs in the RS\_TAX40 scenario are analyzed, the fuel costs, investment costs and other costs are higher than those in the RS\_TAX10 and RS\_TAX20 scenarios.

When the cost results of the CCS scenarios and tax scenarios are compared, it can be seen that the difference among the total costs of those scenarios are negligible except for the RS\_TAX40 scenario. The cost difference of the RS\_TAX40 scenario is mostly caused by investments.

When the costs of the tax scenarios are compared to the costs of nuclear scenarios, fuel costs of the RS\_NUCF scenario is lower than those in the tax scenario towards the end of the planning horizon. However, investment costs of the RS\_NUCF scenario are higher than those in the tax scenarios. Investment costs of the RS\_NUCS scenario are higher than those in the RS\_TAX10 and RS\_TAX20 scenarios.

The investment and fuel costs of the RS\_C\_40 scenario are higher than those in the tax scenarios. Since the model does not treat taxes as penalties, there are no significant changes in the tax scenarios in terms of costs.

#### **5.2.5. The Fuel Price Increase Scenarios**

Turkey is heavily dependent on imported energy resources for most of its electricity generation. Therefore, in this section, fuel price increase scenarios, which are the “40% Fuel Price Increase” and the “80% Fuel Price Increase”, are generated and their results are analyzed in order to see the effects of import dependence of Turkey.

In the “40% Fuel Price Increase” scenario, which is named the RS\_FP40 scenario, the price of natural gas, heavy fuel oil and imported coal is increased by 40% beyond 2016. Likewise, in the “80% Fuel Price Increase” scenario, which is named the RS\_FP80 scenario, the price of natural gas, oil, heavy fuel oil and imported coal is increase by 80% beyond 2016. For the RS\_FP40 and RS\_FP80 scenarios, energy consumptions by



Table 5.29. Energy consumptions of the electricity sector by resources in the RS\_FP80 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.1	5.7	2.9	1.8	0.5	0.0	0.0	0.0
COAL	571.3	536.1	904.2	898.9	1,537.1	2,053.4	2,889.9	3,871.3	5,305.7	6,892.1
DIESEL	3.7	4.5	1.6	1.7	0.4	0.2	0.1	0.0	0.0	0.0
GEOTHERMAL	1.3	10.1	10.5	10.9	11.3	11.7	10.4	9.2	7.9	6.6
HEAVY FUEL OIL	39.3	4.1	9.9	9.9	2.3	1.1	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	394.7	494.7	493.1	493.0	492.2	491.0	489.4	460.0
NATURAL GAS	493.8	735.0	147.9	153.3	23.6	83.2	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	72.0	185.2	182.2	218.7	235.3	248.3	149.0	156.1
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TOTAL	1,328.0	1,529.3	1,546.0	1,760.2	2,252.8	2,862.9	3,628.6	4,619.7	5,952.1	7,514.9

Table 5.30. Share of energy consumptions in the electricity sector by resources in the RS\_FP80 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0
COAL	43.0	35.1	58.5	51.1	68.2	71.7	79.6	83.8	89.1	91.7
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.7	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1
HEAVY FUEL OIL	3.0	0.3	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	14.3	25.5	28.1	21.9	17.2	13.6	10.6	8.2	6.1
NATURAL GAS	37.2	48.1	9.6	8.7	1.0	2.9	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	4.7	10.5	8.1	7.6	6.5	5.4	2.5	2.1
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

As can be inferred from Tables 5.27, 5.28, 5.29 and 5.30, in the 40% and 80% fuel price increase scenarios, natural gas consumption gets lower whereas hydro and wind energy consumptions get higher, compared to those in the base scenario. Also, bio energy consumption is slightly higher than that of the base scenario. Besides, the use of diesel and heavy fuel oil slowly decrease and from 2041, these fuels are not used to generate electricity.

The behavior of coal consumption is of interest: it is increasing in the RS\_FP40 scenario, while it decreases in the RS\_FP80 scenario. In other words, although coal has an increasing trend over the planning horizon in both fuel price scenarios, its consumption in the RS\_FP80 scenario becomes lower than that of the base scenario from 2026 onwards. This is probably because, when domestic lignite reserves are depleted, the model must divert to imported coal. However, because of its high price, amount of imported coal becomes lower than that in the base scenario.

When the fuel price scenarios are compared to the nuclear scenarios, coal consumption in the RS\_NUCF scenario is lower than that of the fuel price scenarios. Coal consumption in the RS\_NUCS scenario is higher than that of the RS\_FP80 scenario, but lower than that of the RS\_FP40 scenario. Moreover, hydro and wind energy consumptions in the nuclear scenarios are lower than those in the fuel price scenarios, but natural gas consumption in the nuclear scenarios are higher than those in the fuel price scenarios. This results show that fuel price scenarios give significant importance to renewables (such as hydro and wind energy).

Similar to the nuclear scenarios, hydro and wind energy consumptions in the CCS scenarios are lower than those in fuel price scenarios, but natural gas consumptions in the CCS scenarios are higher than those in fuel price scenarios. In addition, coal consumptions in the CCS scenarios are lower than those in the RS\_FP40 scenario, but higher than those in the RS\_FP80 scenario.

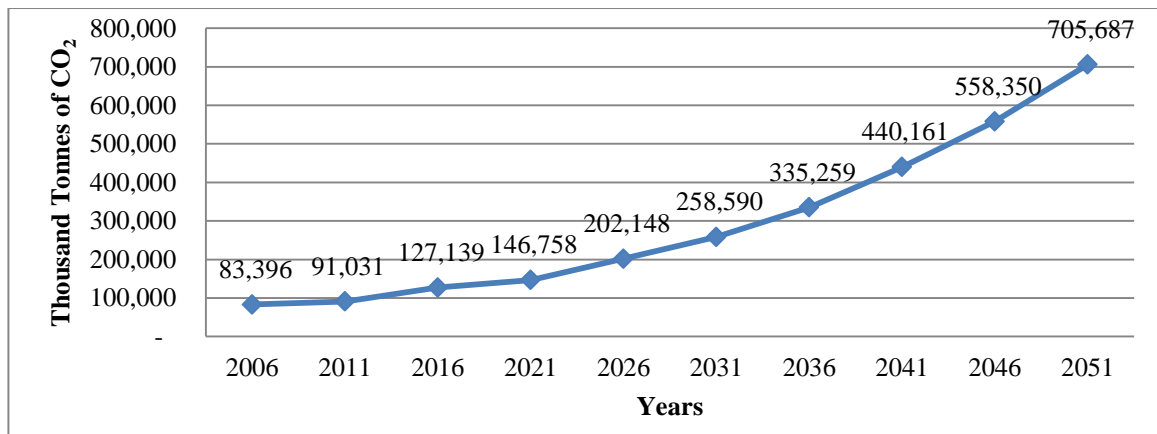


Figure 5.24. CO<sub>2</sub> Emissions of the electricity sector in the RS\_FP40 scenario.

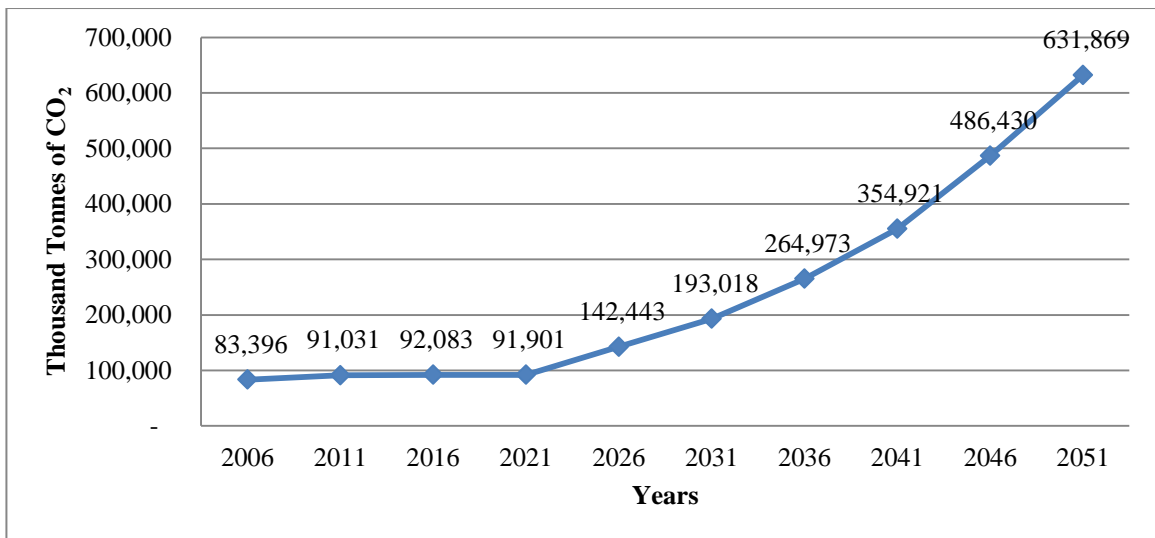


Figure 5.25. CO<sub>2</sub> Emissions of the electricity sector in the RS\_FP80 scenario.

Since coal has a great influence on CO<sub>2</sub> emissions, as its consumption gets lower in the RS\_FP80 scenario, compared to that of the RS\_FP40 scenario, the CO<sub>2</sub> emissions in the RS\_FP80 scenario become lower than those in the RS\_FP40 scenario. Also, it should be mentioned that total electricity sector CO<sub>2</sub> emissions in the RS\_FP40 scenario are higher than those in the base scenario. However, total electricity sector CO<sub>2</sub> emissions in the RS\_FP80 scenario are about 15% lower than those in the base scenario.

Furthermore, when CO<sub>2</sub> emissions of the electricity sector in these fuel price scenarios are compared to those in the emission restriction scenarios, it is obvious that emission restriction scenarios are more environmentally friendly since their CO<sub>2</sub> emissions are lesser. On the other hand, when fuel price scenarios are compared to those in the nuclear scenarios, electricity sector CO<sub>2</sub> emissions in the RS\_NUCF scenario are lower than those in the fuel price scenarios. Electricity sector CO<sub>2</sub> emissions in the RS\_NUCS scenario are higher than those in the RS\_FP80 scenario, but lower than those in the RS\_FP40 scenario.

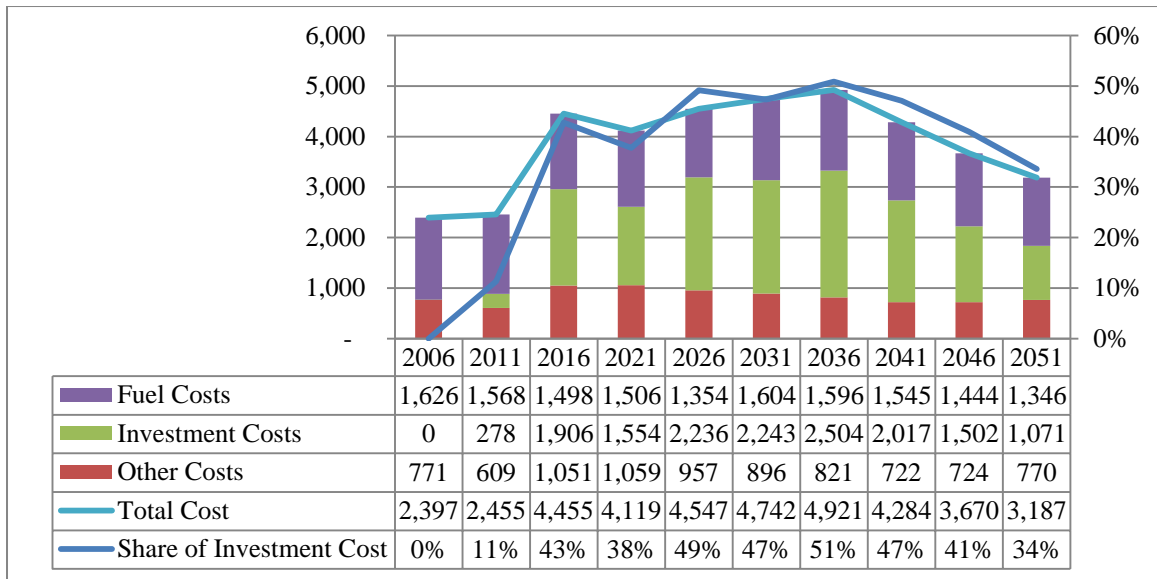


Figure 5.26. Costs of the electricity sector in the RS\_FP40 scenario (M pounds).

When the costs in the RS\_FP40 scenario are compared with the costs in the base scenarios, as can be expected, the most remarkable difference is in the fuel costs (because of the increase in the fuel prices by 40%). It also should be mentioned that, though the total costs of the electricity sector increases, the share of investment cost decreases compared to the base scenario (the difference of the investment costs between these scenarios being very low).

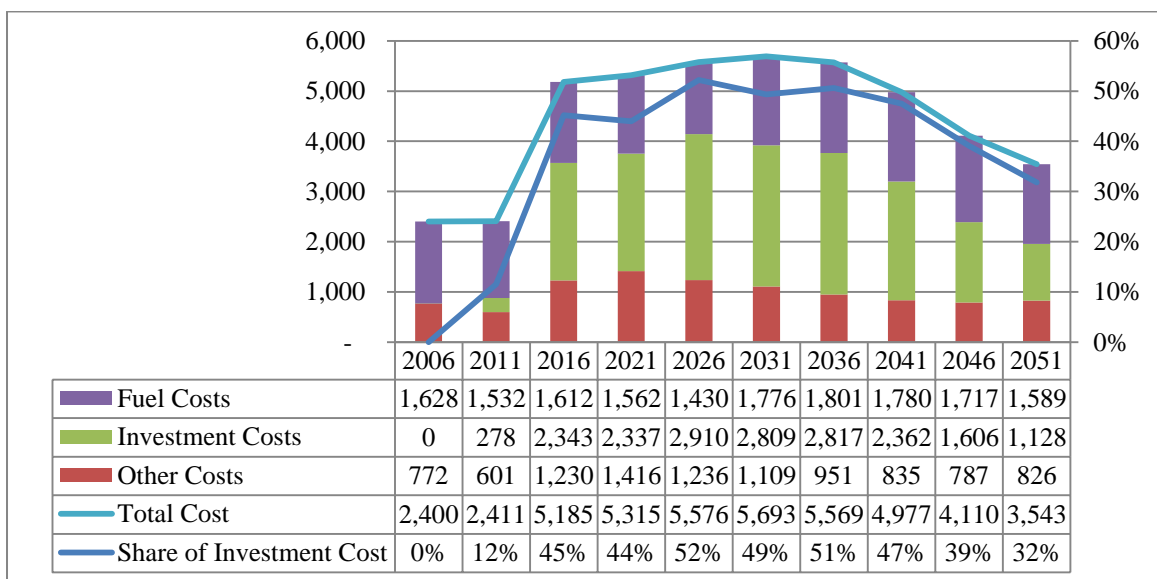


Figure 5.27. Costs of the electricity sector in the RS\_FP80 scenario (M pounds).

When the costs in the RS\_FP80 scenario are compared to the costs in the RS\_FP40 scenario, it can be seen that total fuel costs are up 9%, while total costs are up to 15%. On the other hand, investment costs are up to 21%. In 2016, the year which fuel prices are started to increase, the investment costs are increased sharply in these two scenarios because the model invest in new technologies, such as wind and bio energy technologies.

Additionally, when the costs of these fuel price scenarios are compared to those in the emission restriction scenarios, the fuel costs in the RS\_C\_20 scenario are lower than those in the fuel price scenarios, but the fuel costs in the RS\_C\_40 scenarios are lower than those in the fuel price scenarios from 2031 onwards. Total electricity costs in the fuel price scenarios are lower than those in the RS\_C\_40 scenario, but higher than those in the RS\_C\_20 scenario. This shows that reducing CO<sub>2</sub> emissions 40% is fairly expensive. When the costs in the fuel price scenarios are compared to those in the nuclear scenarios, it can be observed that fuel costs are higher and investment costs are lower than those in the nuclear scenarios. The underlying reason is that nuclear power installation is fairly costly but nuclear power utilization does not result in high fuel costs. Total electricity sector costs in the RS\_FP80 scenario are the highest among the fuel price and the nuclear scenarios. Total electricity sector costs in the RS\_FP40 scenario are lower than those in the RS\_NUCF scenario and higher than the RS\_NUCS scenario. This is mostly due to high fuel prices in the RS\_FP80 scenario.

#### **5.2.6. The Emission Restriction and Tax Scenario**

The following scenarios are the “combination scenarios” which are accomplished by combining the previous individual scenarios. Henceforth, in the following subsections, new scenarios are created by binary, ternary or quadruple combinations of these individual scenarios.

In the first combination scenario, which is named the C\_40TAX2 scenario, 40% emission reduction scenario is integrated with the 20 TL tax per tonne of CO<sub>2</sub> scenario, in order to measure the combined effects of emission reduction enforcement and taxes. Energy consumptions of this scenario are depicted in Tables 5.31 and 5.32.

Table 5.31. Share of energy consumptions in the electricity sector by resources in the C\_40TAX2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.8	6.0	2.6	0.9	0.0	0.0	0.0	0.0
COAL	571.3	348.1	0.0	22.0	752.0	1,510.6	2,613.7	3,956.8	5,288.4	7,368.2
DIESEL	4.6	3.9	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1
GEOTHERMAL	1.3	10.1	10.5	10.9	11.3	11.7	10.4	9.2	7.9	6.6
HEAVY FUEL OIL	38.4	0.8	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	532.0	532.4	532.2	531.6	506.7	498.5	492.4	451.3
NATURAL GAS	492.8	735.0	373.6	735.0	633.3	639.3	515.3	539.3	650.1	672.5
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	141.9	185.2	187.6	218.7	235.3	178.4	168.1	184.7
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TOTAL	1,326.9	1,337.5	1,063.7	1,491.4	2,118.9	2,912.7	3,881.8	5,182.1	6,607.0	8,683.4

Table 5.32. Share of energy consumptions in the electricity sector by resources in the C\_40TAX2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.5	0.4	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.1	26.0	0.0	1.5	35.5	51.9	67.3	76.4	80.0	84.9
DIESEL	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.8	1.0	0.7	0.5	0.4	0.3	0.2	0.1	0.1
HEAVY FUEL OIL	2.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	16.3	50.0	35.7	25.1	18.3	13.1	9.6	7.5	5.2
NATURAL GAS	37.1	55.0	35.1	49.3	29.9	21.9	13.3	10.4	9.8	7.7
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.4	13.3	12.4	8.9	7.5	6.1	3.4	2.5	2.1
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

As shown in Table 5.32, when CO<sub>2</sub> emissions are bounded and tax is applied on CO<sub>2</sub> emissions beyond the year 2016, the consumption of coal (which is the main contributor of CO<sub>2</sub> emissions in electricity generation sector) immediately decreases to zero. The most dominant fuel resource becomes hydro energy, and then natural gas (whose consumptions in this scenario are higher than those in the base scenario) follows it. However, over the planning horizon, the consumption of coal quickly rebounds and steadily increases again to become the most dominant fuel type (with 84.9%) by the end of the planning horizon. Also, the consumption of hydro energy decreases each year but it is still greater than its level in the base scenario.

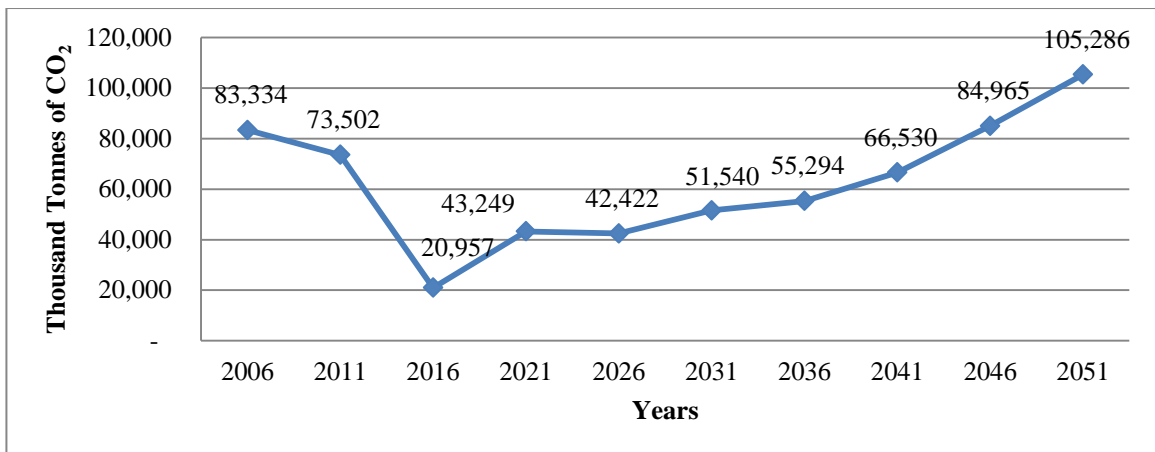


Figure 5.28. CO<sub>2</sub> Emissions of the electricity sector in the C\_40TAX2 scenario.

As can be seen in Figure 5.28, in this scenario the total CO<sub>2</sub> emissions are initially reduced by 40% (in 2016, which is the period that the constraints of this scenario become active). Because of the emission restriction and tax applications, CO<sub>2</sub> emissions in this scenario are lower than those in the base scenario. The decreasing rate of the CO<sub>2</sub> emissions is 67% in 2021 and 85% at the end of the planning horizon compared to the base scenario. On the other hand, the level of CO<sub>2</sub> emission over the planning horizon is the same as the one in RS\_C\_40.

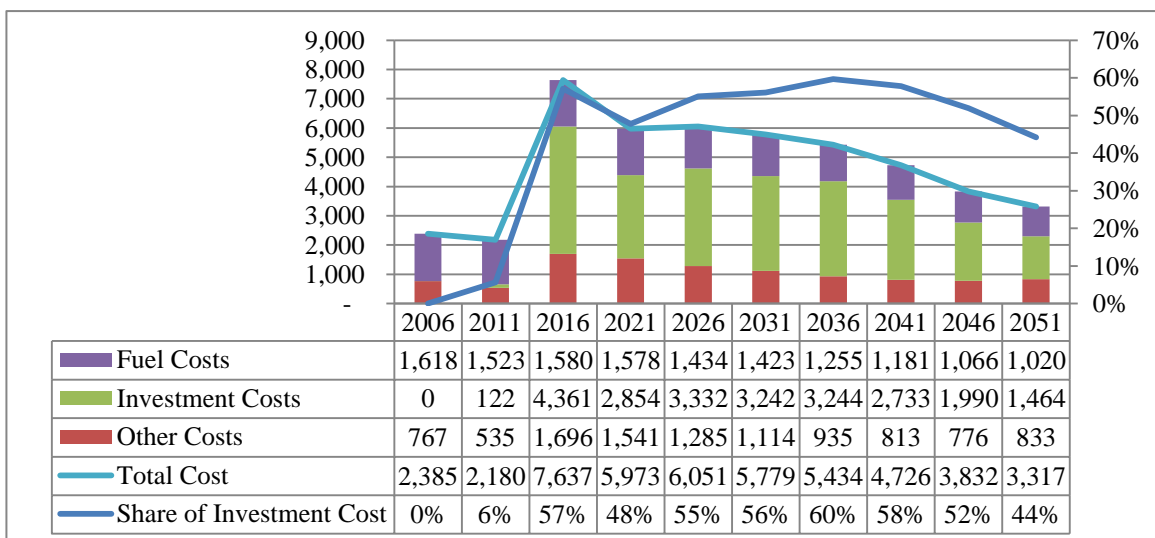


Figure 5.29. Costs of the electricity sector in the C\_40TAX2 scenario (M pounds).

As shown in Figure 5.28, in the C\_40TAX2 scenario, there is a sharp increase in the investment costs in 2016 (while there is some decrease in). Since CO<sub>2</sub> emissions are reduced by 40% and tax is applied per tonne of CO<sub>2</sub>, the model invests in new technologies that result in high investment costs (instead of using conventional technologies which use fossil fuel energy carriers). When these costs are compared with costs in the base scenario, total cost in the base scenario is lower than the total cost of this scenario. Also, the fuel cost of this alternative scenario is higher than the fuel cost of the base scenario (except for the last two periods). It is worth mentioning that the costs in the C\_40TAX2 scenario are nearly the same as those in the RS\_C\_40 scenario likewise CO<sub>2</sub> emissions.

### 5.2.7. The Emission Restriction and Fuel Price Increase Scenario

In this scenario, which is named as “C\_40FP80”, the 40% emission reduction constraint is combined with the 80% fuel price increase, in order to see their combined influence the electricity sector. Energy consumptions by resources and share of these resources for electricity sector in this scenario are displayed in Tables 5.33 and 5.34, respectively.

Table 5.33. Energy consumptions of the electricity sector by resources in the C\_40FP80 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	3.0	4.5	5.7	1.9	0.9	0.0	0.0	0.0	0.0
COAL	571.3	314.0	68.3	319.7	141.5	82.0	926.5	925.0	2,332.5	4,227.7
DIESEL	3.7	3.9	0.0	0.3	0.1	0.1	0.1	0.0	0.0	0.0
GEOTHERMAL	1.3	10.1	10.5	10.9	11.3	11.7	10.4	9.2	7.9	6.6
HEAVY FUEL OIL	39.3	0.6	0.0	1.7	0.7	0.7	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	719.4	756.7	755.9	754.5	754.0	753.0	751.6	722.2
NATURAL GAS	493.8	735.0	29.1	24.2	4.1	2.7	2.7	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	141.9	185.2	201.9	265.3	305.1	341.5	377.7	417.6
NUCLEAR	0.0	0.0	0.0	184.6	1,139.9	1,954.0	1,954.0	3,366.1	3,366.1	3,366.1
ANNUAL TOTAL	1,328.0	1,303.8	973.7	1,489.0	2,257.2	3,071.8	3,953.1	5,394.7	6,835.7	8,740.3

Table 5.34. Share of energy consumptions in the electricity sector by resources in the C\_40FP80 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.5	0.4	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	24.1	7.0	21.5	6.3	2.7	23.4	17.1	34.1	48.4
DIESEL	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.8	1.1	0.7	0.5	0.4	0.3	0.2	0.1	0.1
HEAVY FUEL OIL	3.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	16.8	73.9	50.8	33.5	24.6	19.1	14.0	11.0	8.3
NATURAL GAS	37.2	56.4	3.0	1.6	0.2	0.1	0.1	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.4	14.6	12.4	8.9	8.6	7.7	6.3	5.5	4.8
NUCLEAR	0.0	0.0	0.0	12.4	50.5	63.6	49.4	62.4	49.2	38.5
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

As can be inferred from Table 5.33, in this scenario forced by the combined effect of emission restrictions and high fuel costs, the model starts to use nuclear energy by 2021. Since there are no bounds on nuclear energy in this scenario, it increases to unrealistically high levels (up to 60%), stabilizing at 38% at the end of the planning horizon. Although coal consumption decreases until 2016, its share increases after 2021 and still becomes dominant at the end of the planning horizon. Due to the increasing fuel prices, the model prefers to consume minimum natural gas, heavy fuel oil and diesel in electricity generation, so their fuel share is almost 0 by 2041.

The combined effect of emission restriction and fuel price increases is also visible on hydro and wind energy usage. They both display significant increases (50.8% and 12.4% in 2021) slowly declining to 8.3% and 4.8% by the end of the planning horizon. Bio energy consumption is also higher than that of the base scenario.

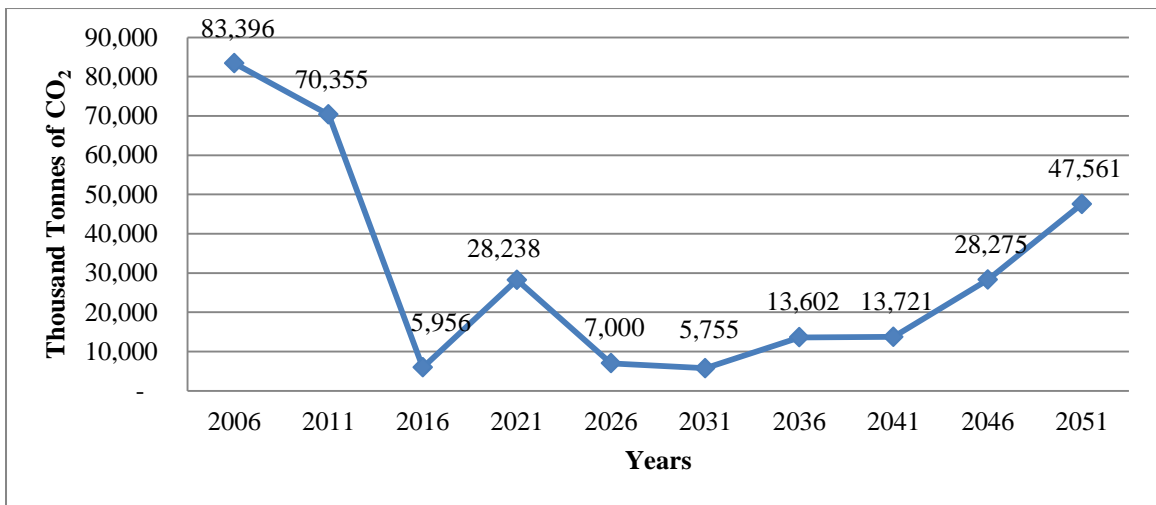


Figure 5.30. CO<sub>2</sub> Emissions of the electricity sector in the C\_40FP80 scenario.

When the results of the BASE, C\_40FP80, RS\_FP80 and RS\_C\_40 scenarios are analyzed, it can be seen that the combined effects of emission reductions and fuel price changes on CO<sub>2</sub> emissions is considerable. The electricity sector CO<sub>2</sub> emissions in the RS\_C\_40 scenario are lower than those in the RS\_FP80 scenario. However, in this combined scenario, the electricity sector CO<sub>2</sub> emissions are the lowest compared to these individual scenarios (the RS\_C\_40 and the RS\_FP80 scenarios). The decreasing rate of the electricity sector CO<sub>2</sub> emissions in the RS\_C\_40 and the RS\_FP80 scenarios (compared to those in the base scenario) are 29% and 67% in 2021 and 9% and 85% by the end of the planning horizon. On the other hand, the decreasing rate of the electricity sector CO<sub>2</sub> emissions in the C\_40FP80 scenario is 94% in 2021 and 93% by the end of the planning horizon.

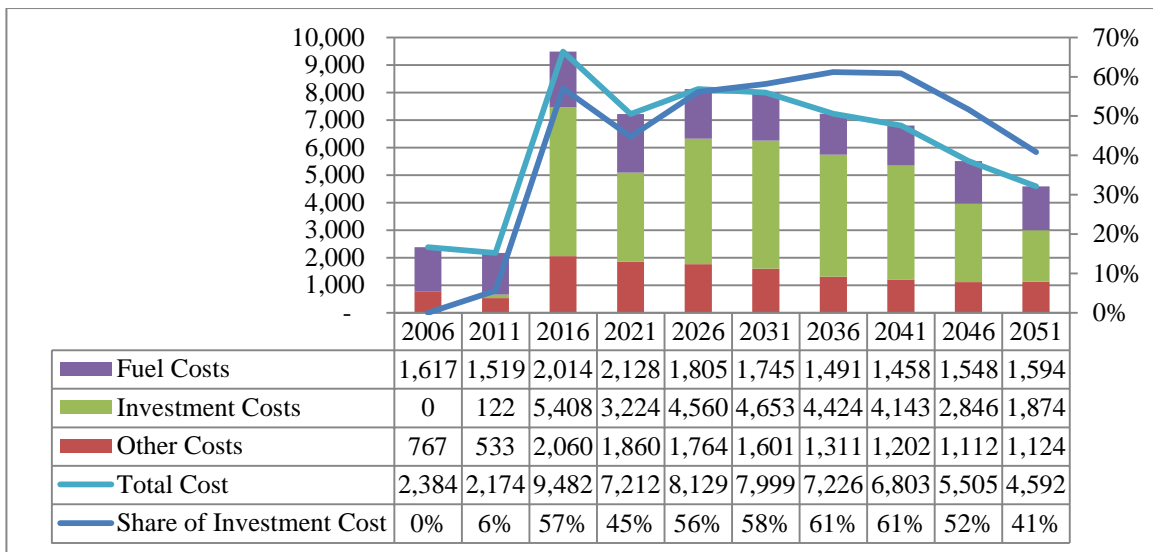


Figure 5.31. Costs of the electricity sector in the C\_40FP80 scenario (M pounds).

As can be seen in Figure 5.31, in the C\_40FP80 scenario, there is a high increase in investment costs compared to the base scenario. Since the model is forced to decrease CO<sub>2</sub> emission levels, there are investments in green technologies. Fuel costs are higher than those of the base scenario because of the increased fuel prices. At the end of the planning horizon, the total cost of the electricity sector in this alternative scenario is about two-fold higher than the total cost of the electricity sector in the base scenario.

### 5.2.8. The Fuel Price Increase and Emission Tax Scenario

In this scenario, which is named the FP80TAX2 scenario, the 80% fuel price increase scenario is integrated with the 20 TL tax per ton of CO<sub>2</sub> scenario in order to measure the combined effects of fuel price increases and taxes. Energy consumptions by resources and share of these resources for the electricity sector for the FP80TAX2 scenario are displayed in Tables 5.35 and 5.36, respectively.

Table 5.35. Energy consumptions of the electricity sector by resources in the FP80TAX2 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.1	5.7	3.6	2.6	0.9	0.0	0.0	0.0
COAL	571.3	536.1	801.8	798.7	1,340.4	1,606.4	2,420.9	3,389.1	4,802.4	6,380.2
DIESEL	3.7	4.5	1.6	1.7	0.3	0.2	0.1	0.0	0.0	0.0
GEOTHERMAL	1.3	10.1	10.5	10.9	11.3	11.7	10.4	9.2	7.9	6.6
HEAVY FUEL OIL	39.3	4.1	9.9	9.9	1.6	1.1	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	451.3	532.4	531.6	530.8	530.0	528.7	527.2	497.9
NATURAL GAS	493.8	735.0	105.9	121.5	28.8	59.9	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	72.0	185.2	192.4	265.3	281.9	294.9	214.7	231.2
NUCLEAR	0.0	0.0	0.0	0.0	0.0	314.9	314.9	314.9	314.9	314.9
ANNUAL TOTAL	1,328.0	1,529.3	1,458.0	1,665.9	2,110.0	2,792.8	3,559.3	4,536.7	5,867.0	7,430.9

Table 5.36. Share of energy consumptions in the electricity sector by resources in the FP80TAX2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.4	0.3	0.2	0.1	0.0	0.0	0.0	0.0
COAL	43.0	35.1	55.0	47.9	63.5	57.5	68.0	74.7	81.9	85.9
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.7	0.7	0.7	0.5	0.4	0.3	0.2	0.1	0.1
HEAVY FUEL OIL	3.0	0.3	0.7	0.6	0.1	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	14.3	31.0	32.0	25.2	19.0	14.9	11.7	9.0	6.7
NATURAL GAS	37.2	48.1	7.3	7.3	1.4	2.1	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	4.9	11.1	9.1	9.5	7.9	6.5	3.7	3.1
NUCLEAR	0.0	0.0	0.0	0.0	0.0	11.3	8.8	6.9	5.4	4.2
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

As can be seen in Table 5.35, natural gas and heavy fuel oil consumptions have a decreasing trend and they are not consumed beyond 2041. It is worth mentioning that natural gas consumption has an increasing trend in the RS\_TAX20 scenario but a decreasing trend in this combined and the RS\_FP80 scenarios. Even though, coal consumption has an increasing trend in this scenario, it is lower than that of the base, RS\_FP80 and RS\_TAX20 scenarios. On the other hand, hydro energy consumption is about 2 or 3 folds higher than that of the base scenario and its increasing trend lasts until 2031. Hydro energy consumption is also higher than that of the RS\_FP80 and RS\_TAX20

scenarios. Furthermore, wind energy consumption is higher than that of the base, RS\_FP80 and RS\_TAX20 scenarios and it has an increasing trend over the planning horizon. Besides, nuclear power generation is starting by 2031. After 2031, although its consumption remains the same, its share decreases over the planning horizon since total electricity generation is increasing each period. One key reason of this increase in renewables and clean energy alternatives and decrease in fossil fuels is the high fuel price of fossil fuels. Tax application is another factor of this shifting from fossil fuels to renewables.

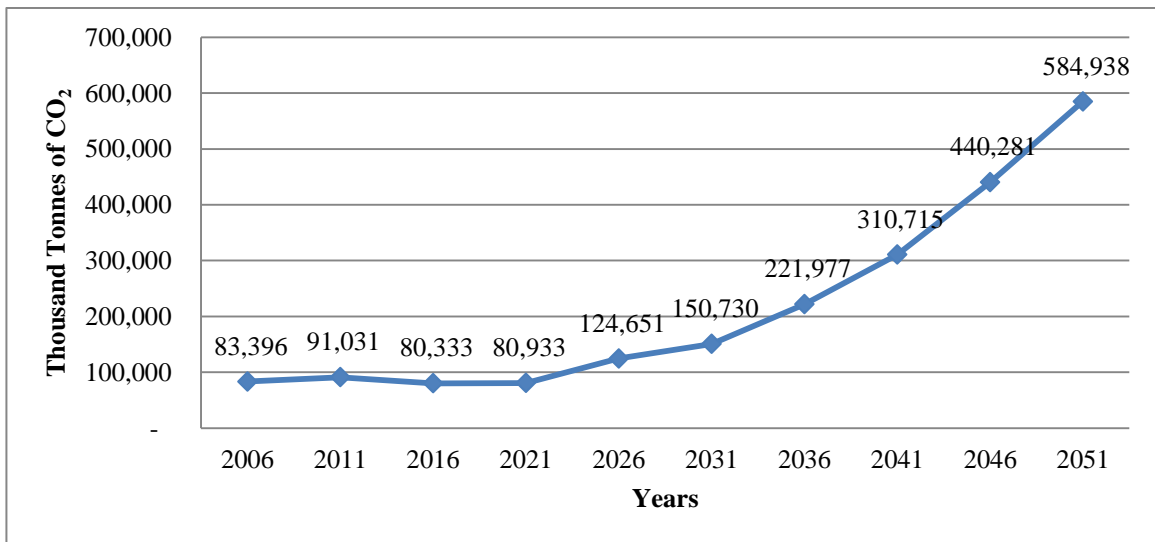


Figure 5.32. CO<sub>2</sub> Emissions of the electricity sector in the FP80TAX2 scenario.

The decrease in fossil fuel consumptions results in lower CO<sub>2</sub> emissions when it is compared to the base scenario. Also, the CO<sub>2</sub> emissions in this scenario are lower than those in the RS\_TAX20 and RS\_FP80 scenarios. The decreasing rate of CO<sub>2</sub> emissions in the FP80TAX2 scenario is 16%, while this rate is 9% in the RS\_FP80 scenario and 5% in RS\_TAX20 scenario (by the end of the planning horizon) compared to the base scenario.

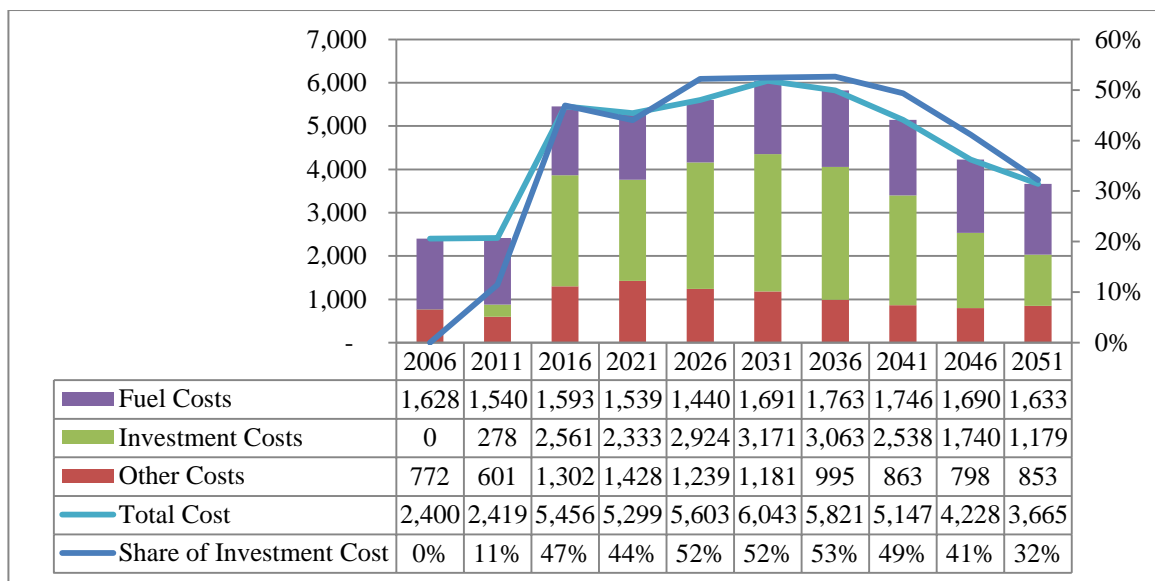


Figure 5.33. Costs of the electricity sector in the FP80TAX2 scenario (M pounds).

The fuel costs of the combined scenario are lower than those in the RS\_FP80 scenario but higher than those in the RS\_TAX20 scenario. Furthermore, investment costs and total cost of this combined scenario are higher than those in the RS\_FP80 and the RS\_TAX20 scenarios. Also, it should be mentioning that all costs in this combined scenario are higher than those in the base scenario. The cost results also support the observation that in this scenario the model encourages green technologies and invests in those technologies.

### 5.2.9. The Emission Restriction, Fuel Price Increase and Tax Scenario

In this scenario, which is named the C4FP80T2 scenario, 40% emission reduction scenario is integrated with 80% fuel price increase and the 20TL tax per ton of CO<sub>2</sub> scenario, in order to measure the combined effects of emission reduction enforcement, 80% fuel price increase and taxes. For the C4FP80T2 scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.37 and 5.38, respectively.

Table 5.37. Energy consumptions of the electricity sector by resources in the C4FP80T2 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	3.0	4.5	5.7	1.9	0.9	0.0	0.0	0.0	0.0
COAL	571.3	314.0	68.3	319.7	141.5	82.0	926.5	925.0	2,332.5	4,227.7
DIESEL	3.7	3.9	0.0	0.3	0.1	0.1	0.1	0.0	0.0	0.0
GEOTHERMAL	1.3	10.1	10.5	10.9	11.3	11.7	10.4	9.2	7.9	6.6
HEAVY FUEL OIL	39.3	0.6	0.0	1.7	0.7	0.7	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	719.4	756.7	755.9	754.5	754.0	753.0	751.6	722.2
NATURAL GAS	493.8	735.0	29.1	24.2	4.1	2.7	2.7	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	141.9	185.2	201.9	265.3	305.1	341.5	377.7	417.6
NUCLEAR	0.0	0.0	0.0	184.6	1,139.9	1,954.0	1,954.0	3,366.1	3,366.1	3,366.1
ANNUAL TOTAL	1,328.0	1,303.8	973.7	1,489.0	2,257.2	3,071.8	3,953.1	5,394.7	6,835.7	8,740.3

Table 5.38. Share of energy consumptions in the electricity sector by resources in the C4FP80T2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.5	0.4	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	24.1	7.0	21.5	6.3	2.7	23.4	17.1	34.1	48.4
DIESEL	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.8	1.1	0.7	0.5	0.4	0.3	0.2	0.1	0.1
HEAVY FUEL OIL	3.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	16.8	73.9	50.8	33.5	24.6	19.1	14.0	11.0	8.3
NATURAL GAS	37.2	56.4	3.0	1.6	0.2	0.1	0.1	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.4	14.6	12.4	8.9	8.6	7.7	6.3	5.5	4.8
NUCLEAR	0.0	0.0	0.0	12.4	50.5	63.6	49.4	62.4	49.2	38.5
TOTAL PERCENTAGE	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 5.37 displays that hydro consumption is increasing until 2021. After this period, it has a decreasing trend however it is still higher than that of the base, the RS\_C\_40 and the FP80TAX2 scenarios. Besides, wind energy consumption is increasing each period and its consumption is higher than that of the base, the RS\_C\_40 and the FP80TAX2 scenarios.

On the other hand, diesel consumption is decreasing and it is hardly consumed beyond 2016 because it is one of the high CO<sub>2</sub> emission contributors in the model. The

trend of coal consumption is not regular. However, its consumption is lower than that of the base, the RS\_C\_40 and the FP80TAX2 scenarios and it reaches minimum level in the period 2016. Natural gas consumption sharply decreases after 2011 and it is not consumed anymore after 2041. Moreover, natural gas and heavy fuel oil consumptions in each period are lower than those in the RS\_C\_40 and the FP80TAX2 scenarios. Moreover, the nuclear energy consumption is sharply increasing from 2021 onwards. After coal, nuclear power generation is the second important source of electricity generation in this scenario. Bio energy consumption increases, although geothermal and solar consumptions almost remain the same compared to the base scenario.

It must be mentioned that the energy consumptions in this scenario and the C\_40FP80 scenario are the same, which shows that additional 20 TL tax application does not have any effect in this scenario.

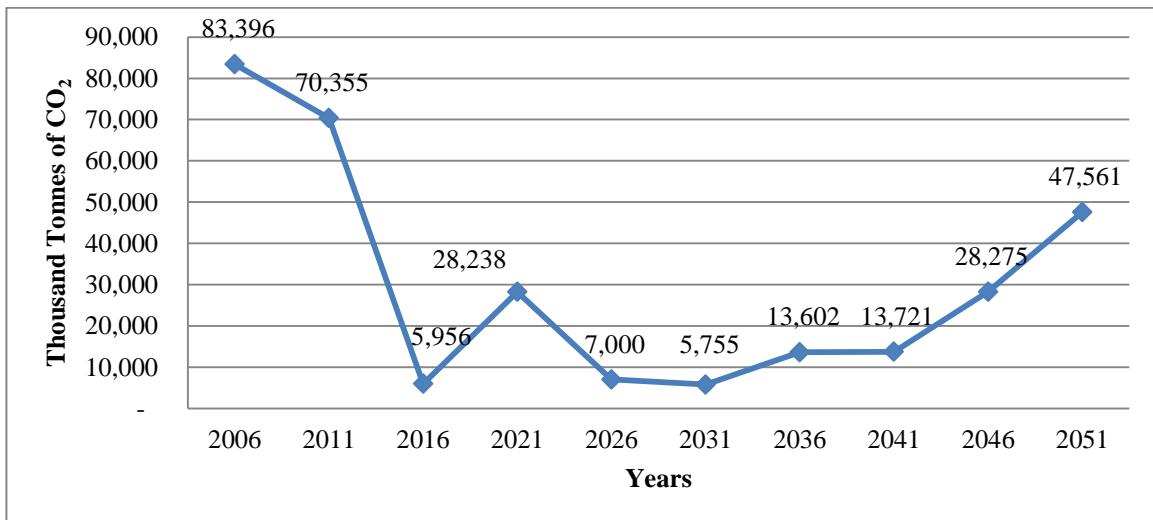


Figure 5.34. CO<sub>2</sub> Emissions of the electricity sector in the C4FP80T2 scenario.

Likewise energy consumptions, the CO<sub>2</sub> emissions are the same as those in the C\_40FP80 scenario. When the results of this scenario are compared to those in the base scenario, the decreasing rate of CO<sub>2</sub> emissions is 93% by the end of the planning horizon. Also, CO<sub>2</sub> emissions in this combined scenario are lower than those in the RS\_FP80, the RS\_C\_40 and the FP\_80TAX2 scenarios.

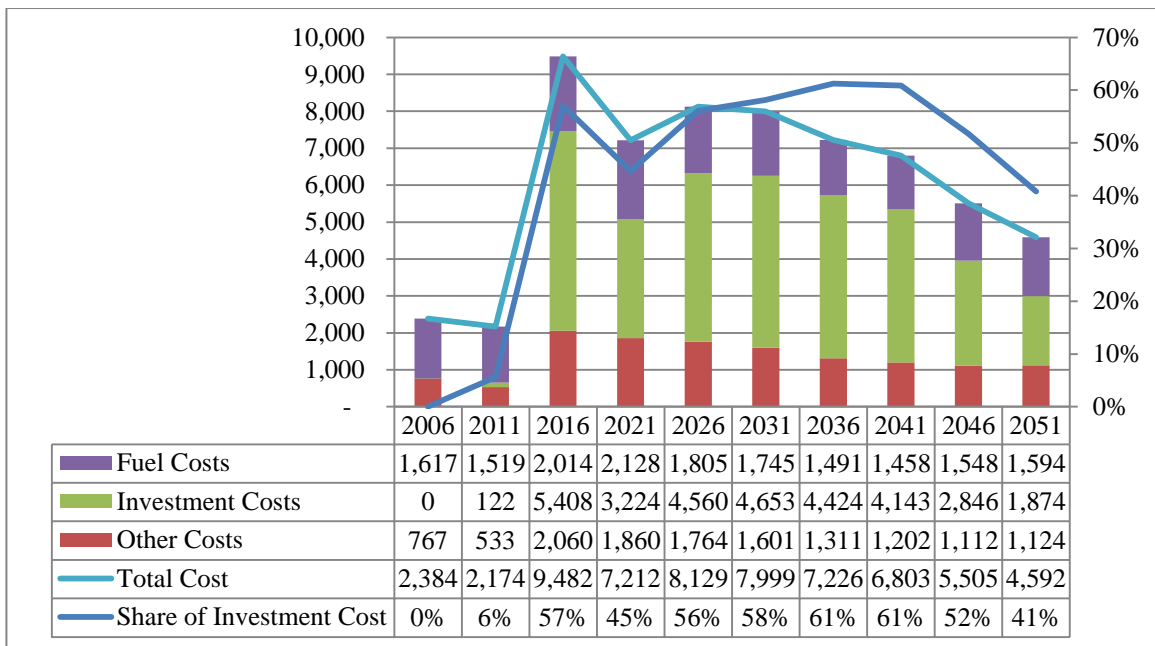


Figure 5.35. Costs of the electricity sector in the C4FP80T2 scenario (M pounds).

The costs of this scenario are almost the same as those in the C\_40FP80 scenario. Additionally, when the costs in this scenario are compared to those in the FP80TAX2 and the RS\_C\_40 scenarios, it can be observed that investment costs and total cost in the C4FP80T2 scenario are higher. Fuel costs in this scenario are also higher than those in the FP80TAX2 and the RS\_C\_40 scenarios till 2036. However, after 2036, the fuel costs in the C4FP80T2 scenario become lower than those in the FP80TAX2 scenario. The primary reason being that the model utilizes less cost energy alternatives (because of the fuel price increase; fuel costs of natural gas, heavy fuel oil and coal get high in this scenario).

### 5.2.10. The Nuclear and Emission Tax Scenario

In this scenario, which is named the in the NUCFTAX2 scenario, the fast nuclear scenario is integrated with 20 TL tax per tonne of CO<sub>2</sub> scenario in order to measure the combined effects of nuclear energy and taxes. For this scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.39 and 5.40, respectively.

Table 5.39. Energy consumptions of the electricity sector by resources in the NUCFTAX2 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.2	4.2	1.9	0.9	0.0	0.0	0.0	0.0
COAL	571.3	536.1	738.5	733.2	1,229.2	1,663.3	2,074.8	2,771.8	3,364.7	4,034.5
DIESEL	3.7	4.5	1.3	1.3	1.1	0.6	0.1	0.1	0.1	0.1
GEOTHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	39.3	4.4	8.6	32.3	7.1	12.2	0.5	0.4	0.4	0.3
HYDRO	218.5	200.4	200.4	200.4	200.3	200.4	199.8	189.5	189.5	180.0
NATURAL GAS	493.8	735.0	481.3	735.0	673.3	684.1	722.6	742.3	924.6	1,177.1
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	61.6	72.2	69.2	86.6	88.8	54.6	48.4	48.4
NUCLEAR	0.0	0.0	140.2	343.8	541.7	821.7	1,200.7	1,717.4	2,392.1	3,285.2
ANNUAL TOTAL	1,328.0	1,511.5	1,652.7	2,138.7	2,740.6	3,487.1	4,302.7	5,489.8	6,931.7	8,735.5

Table 5.40. Share of energy consumptions in the electricity sector by resources in the NUCFTAX2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	35.5	44.7	34.3	44.9	47.7	48.2	50.5	48.5	46.2
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.7	1.0	0.8	0.6	0.5	0.4	0.2	0.2	0.1
HEAVY FUEL OIL	3.0	0.3	0.5	1.5	0.3	0.3	0.0	0.0	0.0	0.0
HYDRO	16.5	13.3	12.1	9.4	7.3	5.7	4.6	3.5	2.7	2.1
NATURAL GAS	37.2	48.6	29.1	34.4	24.6	19.6	16.8	13.5	13.3	13.5
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	3.7	3.4	2.5	2.5	2.1	1.0	0.7	0.6
NUCLEAR	0.0	0.0	8.5	16.1	19.8	23.6	27.9	31.3	34.5	37.6
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

As it is displayed in Table 5.39, bio energy, diesel and heavy fuel oil consumptions are slightly lower than those in the base scenario. Although coal has an increasing trend until 2041, its consumption is lower than that of the base scenario over the planning horizon.

On the other hand, hydro energy consumption is higher than that of the base scenario over the planning horizon, but it has a decreasing trend beyond 2031. Natural gas consumption is also higher than that of the base scenario, but has an increasing profile

except for the period 2026. Geothermal energy consumption is also increasing due to the increased geothermal capacity. At the end of the planning horizon, nuclear power becomes the second important source of electricity with a share of 37.6%.

When the results of this scenario are compared to the RS\_NUCF and the RS\_TAX20 scenarios, coal consumption this combined scenario is the lowest in each period. Natural gas consumption is higher than that of the RS\_NUCF and the RS\_TAX20 scenarios, while hydro energy consumption is higher than that of the RS\_NUCF scenario. As, consumptions of relatively clean energy types (natural gas, nuclear energy and hydro) get higher, dependence on coal is greatly reduced.

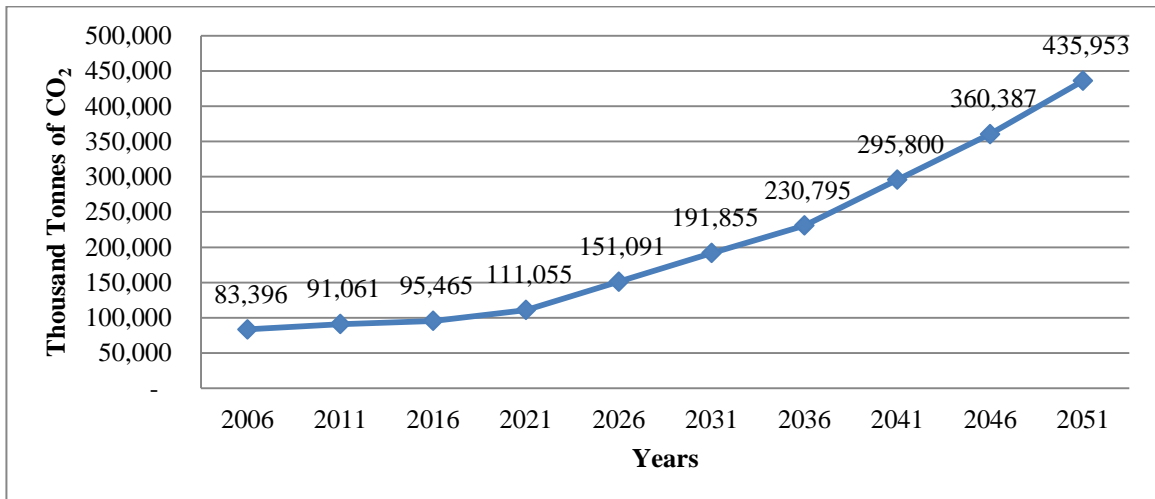


Figure 5.36. CO<sub>2</sub> Emissions of the electricity sector in the NUCFTAX2 scenario.

Although CO<sub>2</sub> emissions in this scenario have an increasing trend, the amount of CO<sub>2</sub> emission is lower than those in the base scenario. When the emission results of the RS\_NUCF, RS\_TAX20 and NUCFTAX2 scenarios are compared, it can be seen that the CO<sub>2</sub> emissions in the RS\_NUCF scenario is lower than those in RS\_TAX20 scenario and but CO<sub>2</sub> emissions in the NUCFTAX2 scenario are the lowest.

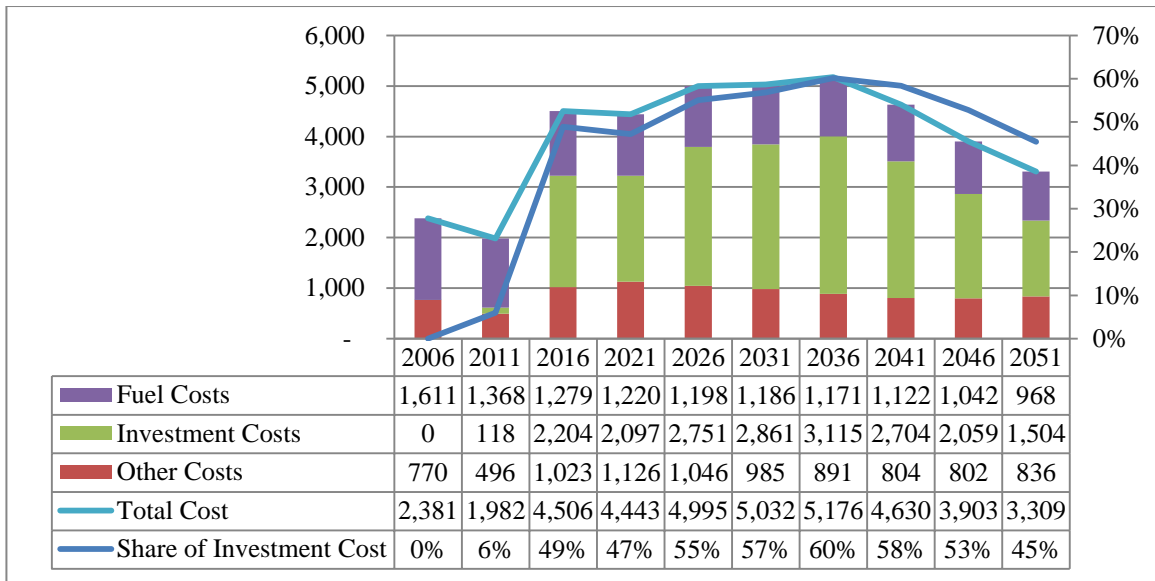


Figure 5.37. Costs of the electricity sector in the NUCFTAX2 scenario (M pounds).

As can be inferred from Figure 5.36, the investment cost in the electricity generation sector is highest compared to the base, the RS\_NUCF and RS\_TAX20 scenarios because of the greater investments into nuclear power plants and clean energy types. However, in this scenario, towards the end of the planning horizon, fuel costs of the electricity sector become lower than those in the base scenario, since nuclear power and other clean energy types have less fuel costs.

### 5.2.11. The Nuclear and Fuel Price Increase Scenario

In this scenario, which is named the NUCFFP80 scenario, the fast nuclear scenario is integrated with the 80% fuel price increase scenario in order to measure the combined effects of nuclear energy and fuel price increase. For this scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.41 and 5.42, respectively.

Table 5.41. Energy consumptions of the electricity sector by resources in the NUCFFP80 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.1	5.7	2.9	0.9	0.0	0.0	0.0	0.0
COAL	571.3	536.1	944.3	939.1	1,340.8	1,486.6	2,163.1	2,765.4	3,717.3	4,653.2
DIESEL	3.7	4.5	1.6	1.7	0.4	0.2	0.1	0.0	0.0	0.0
GEOTHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	39.3	4.1	9.9	9.9	2.3	1.1	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	363.2	394.6	393.2	393.2	392.2	391.0	389.6	360.4
NATURAL GAS	493.8	735.0	88.1	94.6	24.6	27.8	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	72.0	185.2	182.2	218.7	235.3	248.3	149.0	156.1
NUCLEAR	0.0	0.0	162.2	410.2	621.2	1,211.5	1,320.2	1,859.7	2,589.3	3,564.8
ANNUAL TOTAL	1,328.0	1,529.3	1,662.2	2,057.2	2,584.5	3,357.4	4,126.8	5,278.1	6,857.1	8,744.4

Table 5.42. Share of energy consumptions in the electricity sector by resources in the NUCFFP80 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.3	0.3	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	35.1	56.8	45.6	51.9	44.3	52.4	52.4	54.2	53.2
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.7	0.9	0.8	0.7	0.5	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	3.0	0.3	0.6	0.5	0.1	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	14.3	21.9	19.2	15.2	11.7	9.5	7.4	5.7	4.1
NATURAL GAS	37.2	48.1	5.3	4.6	1.0	0.8	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	4.3	9.0	7.0	6.5	5.7	4.7	2.2	1.8
NUCLEAR	0.0	0.0	9.8	19.9	24.0	36.1	32.0	35.2	37.8	40.8
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

Wind and hydro energy consumptions increase until 2041 and are higher than those in the base scenario. Besides, geothermal consumption is also higher. Natural gas is not consumed beyond 2036 and diesel and heavy fuel are also not consumed after 2041. Coal consumption is decreased in this scenario compared to that of the base scenario (it has 53.2% share at the end of the planning horizon). Although there are increased fuel prices of imported coal and enforcement of nuclear power, it is still the dominant energy resource at the end of the planning horizon.

When the results of this scenario are compared to the RS\_NUCF and the RS\_FP80 scenarios, it can be observed that there is decrease in the consumption of natural gas, heavy fuel is also lower than that of the RS\_NUCF scenario. Furthermore, hydro consumption is lower than that of the RS\_FP80 scenario, but higher than that of the RS\_NUCF scenario. After 2021, coal consumption becomes lesser than that of the RS\_FP80 scenario, since the energy consumption shifts from coal to nuclear energy compared to that of the RS\_FP80 scenario. Wind energy consumption in this scenario and in the RS\_FP80 scenario is nearly the same. These are interesting impacts of the considered combination of fuel price increases and nuclear enforcement.

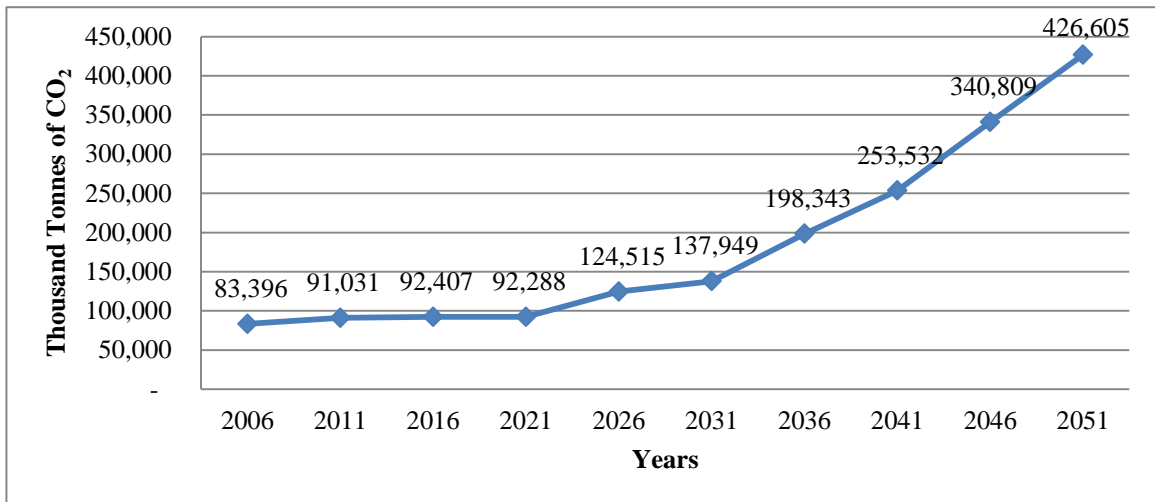


Figure 5.38. CO<sub>2</sub> Emissions of the electricity sector in the NUCFFP80 scenario.

CO<sub>2</sub> emissions in this scenario have the expected increasing trend, but they are lower than those in the base, RS\_NUCF, and RS\_FP80 scenarios; since the share of nuclear (as a clean energy) is greater than that of these scenarios. The electricity sector CO<sub>2</sub> emissions are reduced by 39% in the combined scenario (compared to the base scenario), by the end of the planning horizon. This reduction is 35% in the RS\_NUCF scenario and 9% in the RS\_FP80 scenario.

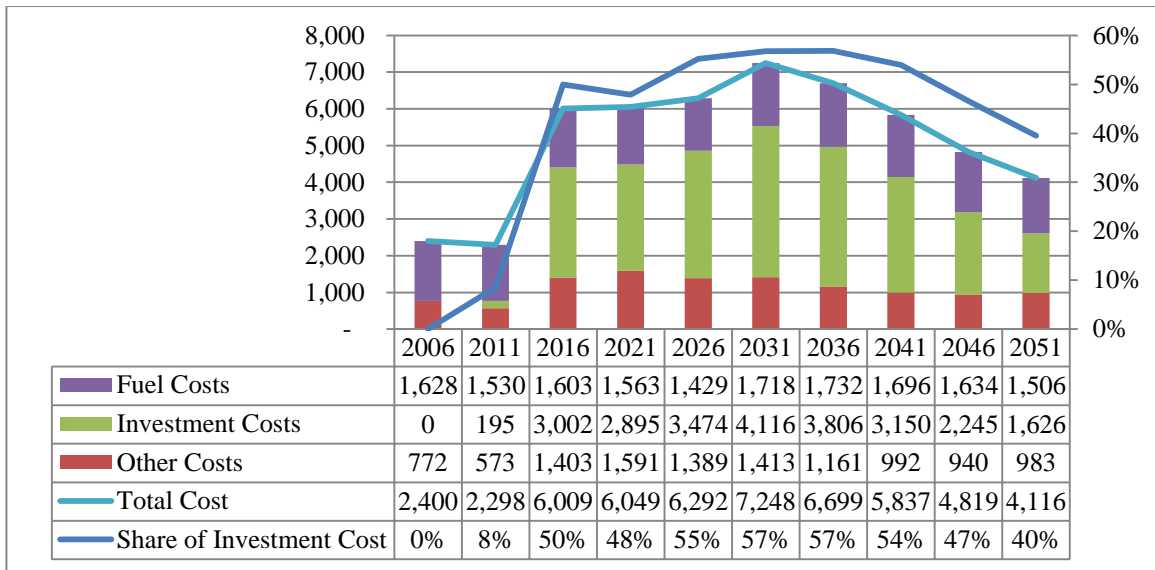


Figure 5.39. Costs of the electricity sector in the NUCFFP80 scenario (M pounds).

As can be inferred from Figure 5.39, there is a prominent increase in the investment costs in 2016 which is the period in which the enforcements are started to be implemented. However, the investment costs in the electricity sector are decreasing after 2031. The fuel costs on the other hand are higher than those in the base scenario. It is worth mentioning that the total cost of the electricity sector in the NUCFTAX2 scenario is lower than that of the NUCFFP80. This result shows that fuel price increase is more costly than the tax application.

### 5.2.12. The Fast Nuclear, Fuel Price Increase and Emission Tax Scenario

In this scenario, which is named the NFP80T2 scenario, the fast nuclear scenario is integrated with the 80% fuel price increase and the 20 TL tax per tonne of CO<sub>2</sub> scenario in order to measure the combined effects of nuclear energy, fuel price increase and taxes. For this scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.43 and 5.44, respectively.

Table 5.43. Energy consumptions of the electricity sector by resources in the NFP80T2 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.1	5.1	2.9	1.8	0.9	0.0	0.0	0.0
COAL	571.3	536.1	745.2	743.4	1,105.4	831.3	1,566.5	2,423.0	3,342.6	4,262.4
DIESEL	3.7	4.5	1.4	1.5	0.3	0.2	0.1	0.0	0.0	0.0
GEOTHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	39.3	4.1	8.4	8.4	2.2	1.1	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	443.4	477.2	476.7	475.9	474.9	473.7	472.3	442.9
NATURAL GAS	493.8	735.0	60.2	59.6	3.6	2.9	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	72.0	185.2	192.4	265.3	281.9	294.9	214.7	231.2
NUCLEAR	0.0	0.0	162.5	411.1	619.0	1,686.0	1,686.0	1,850.4	2,580.7	3,556.2
ANNUAL TOTAL	1,328.0	1,529.3	1,514.1	1,907.8	2,419.3	3,281.8	4,026.1	5,055.7	6,622.0	8,502.7

Table 5.44. Share of energy consumptions in the electricity sector by resources in the NFP80T2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0
COAL	43.0	35.1	49.2	39.0	45.7	25.3	38.9	47.9	50.5	50.1
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.7	1.0	0.9	0.7	0.5	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	3.0	0.3	0.6	0.4	0.1	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	14.3	29.3	25.0	19.7	14.5	11.8	9.4	7.1	5.2
NATURAL GAS	37.2	48.1	4.0	3.1	0.1	0.1	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	4.8	9.7	8.0	8.1	7.0	5.8	3.2	2.7
NUCLEAR	0.0	0.0	10.7	21.5	25.6	51.4	41.9	36.6	39.0	41.8
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

When Tables 5.43 and 5.44 are analyzed, it is seen that results are similar to the previous scenario. The changes brought on by the tax application in this scenario are explained below:

The consumptions of bio energy, hydro, wind and nuclear power generation are greater in this scenario compared to the NUCFFP80 scenario. Furthermore, coal, diesel and natural gas consumptions are decreasing in this scenario. The underlying reason of this

decrease in fossil fuel consumption is the 20 TL tax application on per tonne of CO<sub>2</sub> emission.

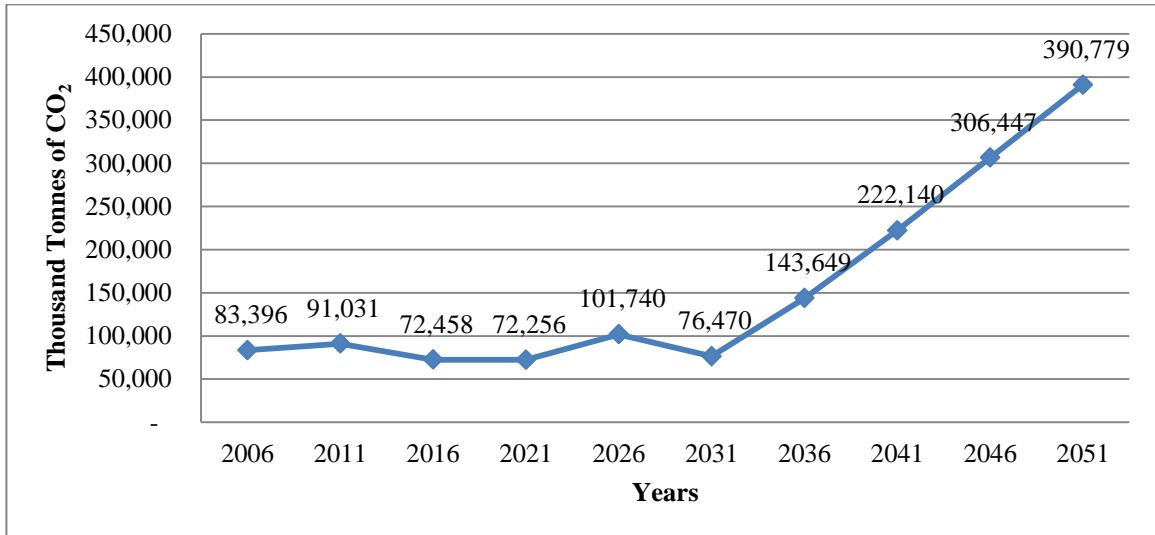


Figure 5.40. CO<sub>2</sub> Emissions of the electricity sector in the NFP80T2 scenario.

When the emission results of this scenario are investigated, it can be seen that, from 2031 onwards, CO<sub>2</sub> emissions are linearly increasing. Coal is the greatest contributor to CO<sub>2</sub> emissions and so the trend of coal consumption is similar to the CO<sub>2</sub> emission of the electricity sector. Besides, since nuclear consumption shifts away the coal consumption, there is a remarkable drop in the amount of CO<sub>2</sub> emissions compared to the base scenario.

Moreover, when the electricity sector CO<sub>2</sub> emission results are analyzed, it can be concluded that the NFP80T2 scenario is more environmentally friendly scenario than the NUCFFP80 scenario because the decreasing rate of CO<sub>2</sub> emissions (compared to the base scenario) is 44% in the NFP80T2 scenario and 39% in the NUCFFP80 scenario.

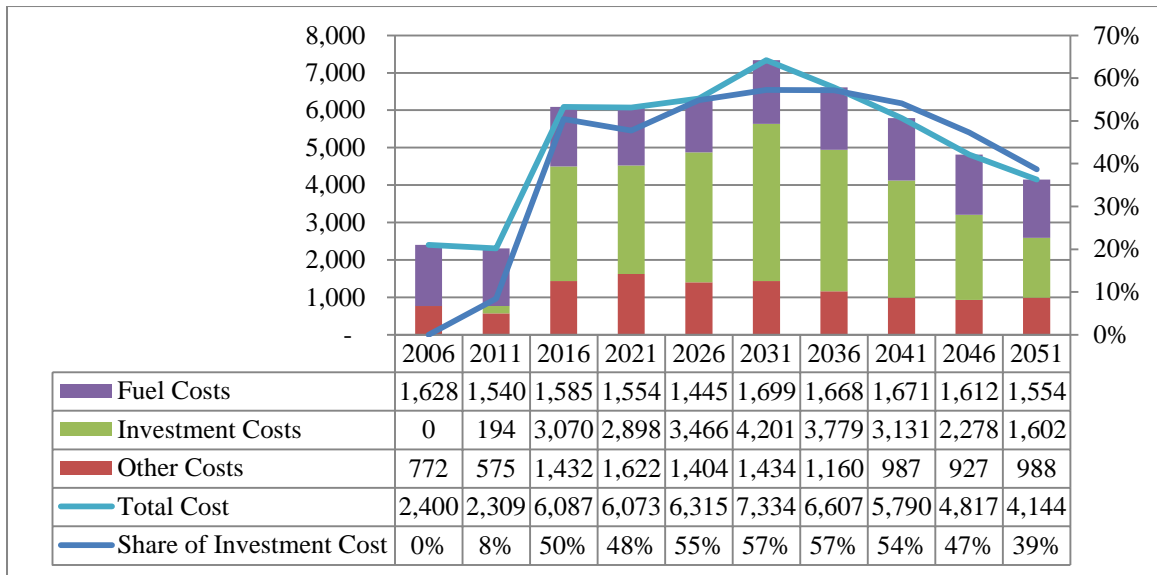


Figure 5.41. Costs of the electricity sector in the NFP80T2 scenario (M pounds).

As it is depicted in Figure 5.41, the most prominent increase in the costs is observed in the investment costs in 2016. Especially, nuclear power usage is the most powerful factor that causes to high investment costs. Other costs are also higher than those in the base scenario because of fuel price increase and tax application. When the costs in the NFP80T2 scenario are compared to the NUCFFP80 scenario, total electricity cost of the NFP80T2 scenario is slightly higher (less than 1%) which is due to 20 TL tax application.

### 5.2.13. The Emission Restriction and Nuclear Scenario

In this scenario, which is named the C\_40NUCF scenario, the 40% emission reduction scenario is integrated with the fast nuclear scenario in order to measure the combined effects of emission reduction enforcement and nuclear energy. For this scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.45 and 5.46, respectively.

Table 5.45. Energy consumptions of the electricity sector by resources in the C\_40NUCF scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.1	5.1	2.0	0.9	0.0	0.0	0.0	0.0
COAL	571.3	349.1	0.0	43.6	517.9	1,020.7	1,686.1	2,486.9	3,015.2	4,284.5
DIESEL	4.6	4.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
GEOTHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	38.4	0.8	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	513.7	516.1	514.1	513.5	492.4	482.6	504.8	444.9
NATURAL GAS	492.8	735.0	321.9	513.0	467.3	485.0	457.7	542.7	856.3	875.4
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	141.9	185.2	187.6	218.7	235.3	178.4	168.1	184.7
NUCLEAR	0.0	0.0	156.0	387.1	576.9	858.3	1,249.5	1,776.0	2,456.8	3,498.6
ANNUAL TOTAL	1,326.9	1,338.5	1,154.4	1,666.4	2,282.7	3,114.9	4,137.0	5,480.3	7,013.0	9,298.1

Table 5.46. Share of energy consumptions in the electricity sector by resources in the C\_40NUCF scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.1	26.1	0.0	2.6	22.7	32.8	40.8	45.4	43.0	46.1
DIESEL	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.8	1.4	1.0	0.7	0.6	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	2.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	16.3	44.5	31.0	22.5	16.5	11.9	8.8	7.2	4.8
NATURAL GAS	37.1	54.9	27.9	30.8	20.5	15.6	11.1	9.9	12.2	9.4
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.4	12.3	11.1	8.2	7.0	5.7	3.3	2.4	2.0
NUCLEAR	0.0	0.0	13.5	23.2	25.3	27.6	30.2	32.4	35.0	37.6
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

As shown in Tables 5.45 and 5.46, there is a decline in the consumption of heavy fuel oil and diesel. Also, natural gas consumption is lower than that of the base scenario except for the last two periods. In the period 2016, coal is not consumed, but it rebounds after this period and becomes the dominant fuel at the end of the planning horizon with 46.1% share. Geothermal, hydro and wind energy consumptions are greater than those in the base scenario. The share of nuclear energy reaches to 37.6% in this scenario.

When the results of this combined scenario are compared to the RS\_C\_40 and the RS\_NUCF scenarios, it can be seen that nuclear energy consumption is higher and coal consumption is lower than those in the individual scenarios. This shows the additional power of the emission restrictions even under the nuclear option (but coal is still the dominant energy resource). Additionally, hydro energy usage in this combined scenario is higher than the RS\_NUCF scenario, but lower than the RS\_C\_40 scenario. Natural gas in the C\_40NUCF is lower than that of the RS\_C\_40 scenario because of the nuclear power usage. Besides, wind energy consumption is higher than that of the RS\_NUCF scenario, but it is nearly the same as that of the RS\_C\_40 scenario.

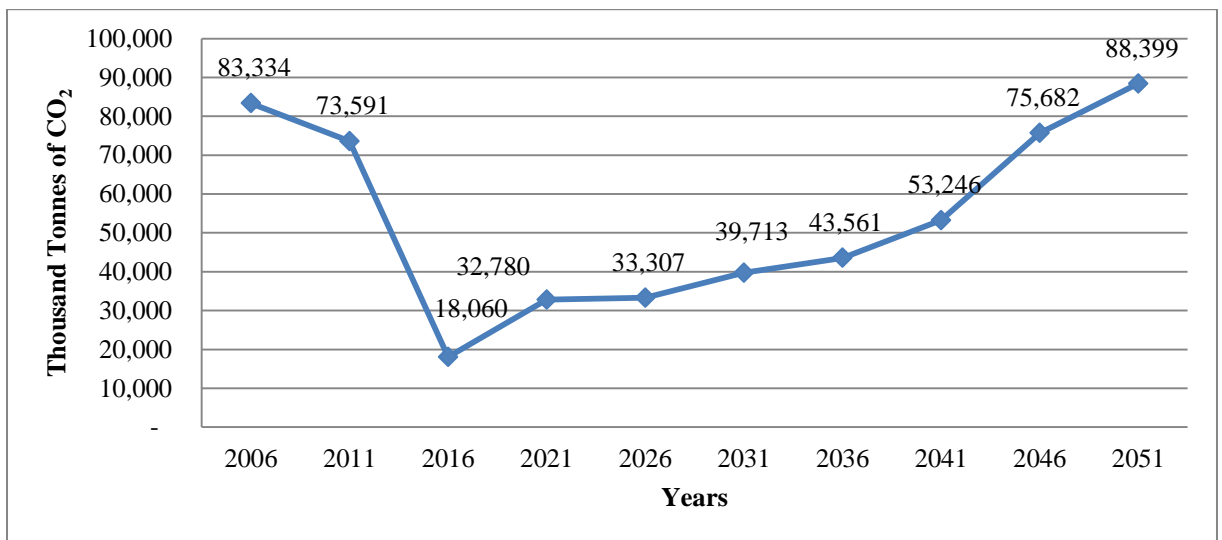


Figure 5.42. CO<sub>2</sub> Emissions of the electricity sector in the C\_40NUCF scenario.

When Figure 5.42 is analyzed, it is seen that there is a sharp decrease in the CO<sub>2</sub> emissions in 2016 compared to the base scenario, due to the fact that most of the coal consumption is replaced (in order to satisfy emission restriction bounds) by the nuclear power, hydro and wind energy to generate electricity. As expected, the emissions rebounds after this date; nevertheless the total emissions are lesser compared to the individual emission restrictions and nuclear scenarios.

The decrease percentage of CO<sub>2</sub> emissions (compared to the base scenario) is 87% in the C\_40NUCF scenario, 85% in the RS\_C\_40 scenario and 34% in the RS\_NUCF scenario.

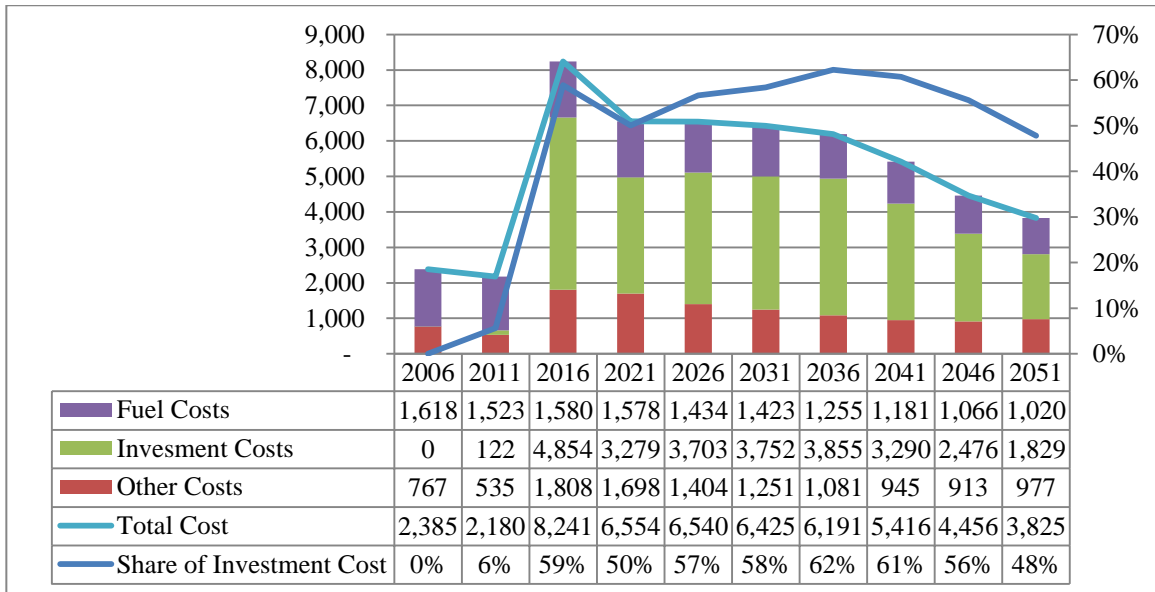


Figure 5.43. Costs of the electricity sector in the C\_40NUCF scenario (M pounds).

As it can be inferred from Figure 5.43, there is a sharp increase in the investment costs compared to those in the base scenario. Besides, fuel costs in the C\_40NUCF scenario are higher until 2041; thereafter they become lower than those in the base scenario. This is because the model invests in clean green technologies, in order to reduce CO<sub>2</sub> emissions. It is worth mentioning that the total cost of this combined scenario is higher than that of the RS\_NUCF and the RS\_C\_40 scenarios.

#### 5.2.14. The Nuclear, Emission Restriction and Tax Scenario

In this scenario, which is named the C4NFT2 scenario, the fast nuclear scenario is integrated with the 40% emission reduction and the 20 TL tax per tonne of CO<sub>2</sub> scenarios in order to measure the combined effects of nuclear energy, emission reduction enforcement and taxes. For this scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.47 and 5.48, respectively.

Table 5.47. Energy consumptions of the electricity sector by resources in the C4NFT2 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.1	5.1	2.0	0.9	0.0	0.0	0.0	0.0
COAL	571.3	349.1	0.0	43.6	517.9	1,020.7	1,686.1	2,486.9	3,015.2	4,284.5
DIESEL	4.6	4.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
GEOTHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	38.4	0.8	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	513.7	516.1	514.1	513.5	492.4	482.6	504.8	444.9
NATURAL GAS	492.8	735.0	321.9	513.0	467.3	485.0	457.7	542.7	856.3	875.4
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	141.9	185.2	187.6	218.7	235.3	178.4	168.1	184.7
NUCLEAR	0.0	0.0	156.0	387.1	576.9	858.3	1,249.5	1,776.0	2,456.8	3,498.6
ANNUAL TOTAL	1,326.9	1,338.5	1,154.4	1,666.4	2,282.7	3,114.9	4,137.0	5,480.3	7,013.0	9,298.1

Table 5.48. Share of energy consumptions in the electricity sector by resources in the C4NFT2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.1	26.1	0.0	2.6	22.7	32.8	40.8	45.4	43.0	46.1
DIESEL	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.8	1.4	1.0	0.7	0.6	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	2.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	16.3	44.5	31.0	22.5	16.5	11.9	8.8	7.2	4.8
NATURAL GAS	37.1	54.9	27.9	30.8	20.5	15.6	11.1	9.9	12.2	9.4
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.4	12.3	11.1	8.2	7.0	5.7	3.3	2.4	2.0
NUCLEAR	0.0	0.0	13.5	23.2	25.3	27.6	30.2	32.4	35.0	37.6
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

The energy consumptions in this scenario and the C\_40NUCF scenario are the same, which show that additional 20 TL tax application does not have any effect.

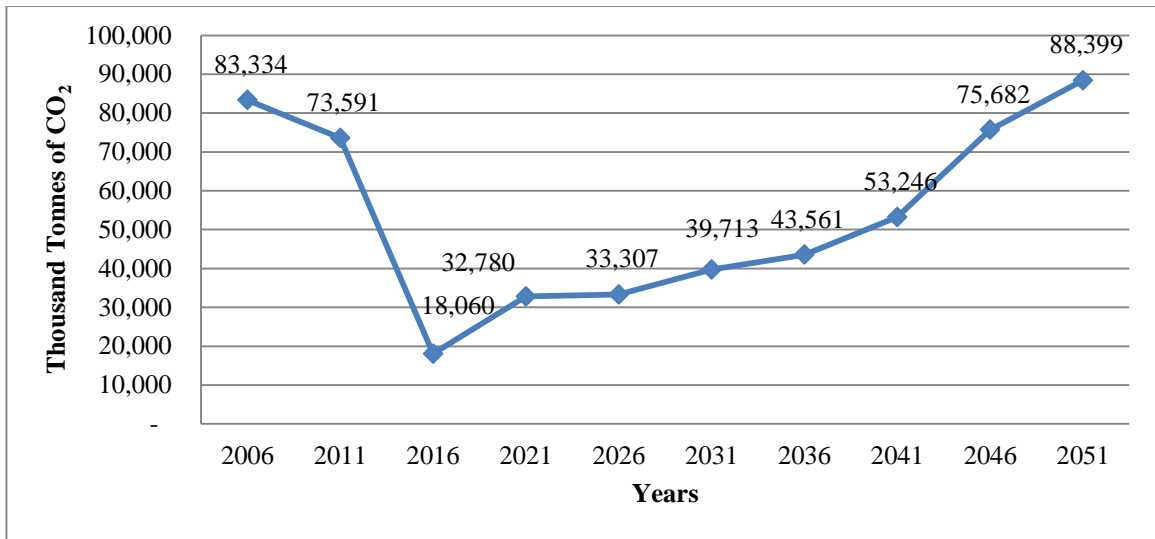


Figure 5.44. CO<sub>2</sub> Emissions of the electricity sector in the C4NFT2 scenario.

Likewise the energy consumptions, the CO<sub>2</sub> emissions are the same as those in the C\_40NUCF scenario.

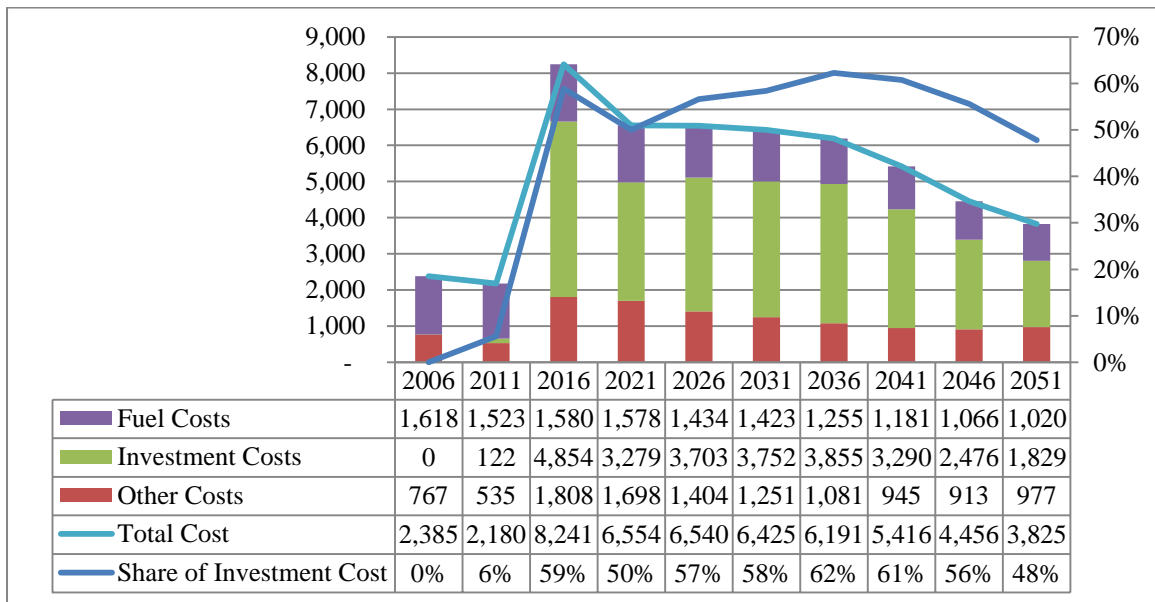


Figure 5.45. Costs of the electricity sector in the C4NFT2 scenario (M pounds).

The costs of this scenario are also the same as those in the C\_40NUCF scenario.



In this scenario; diesel, heavy fuel oil and natural gas consumptions are fast decreasing. The shares of diesel and heavy fuel oil are almost 0 % beyond 2016 and natural gas is not consumed beyond 2041. Coal consumption also has a decreasing trend. Its share drops from 91.2% to 45.5% at the end of the planning horizon.

On the other hand, hydro, wind and geothermal energy consumptions are greater than those in the base scenario. Besides, nuclear power is used about 41.6%. Therefore, especially with the high fuel costs and CO<sub>2</sub> emission restrictions, fossil fuels are not favorable anymore.

When the results of the C4NFFP80 scenario are compared to those in the RS\_FP80 and the C\_40NUCF scenarios, it is seen that consumptions of coal and natural gas are lower than those in the RS\_FP80 and the C\_40NUCF scenarios. Moreover; hydro, wind and nuclear energy consumptions are higher in the C4NFFP80 scenario, compared to those in the RS\_FP80 and the C\_40NUCF scenarios. This shows that as emission reduction and nuclear energy are enforced and fuel prices are increased, the consumption of fossil fuels get lesser and the consumption of renewables get higher.

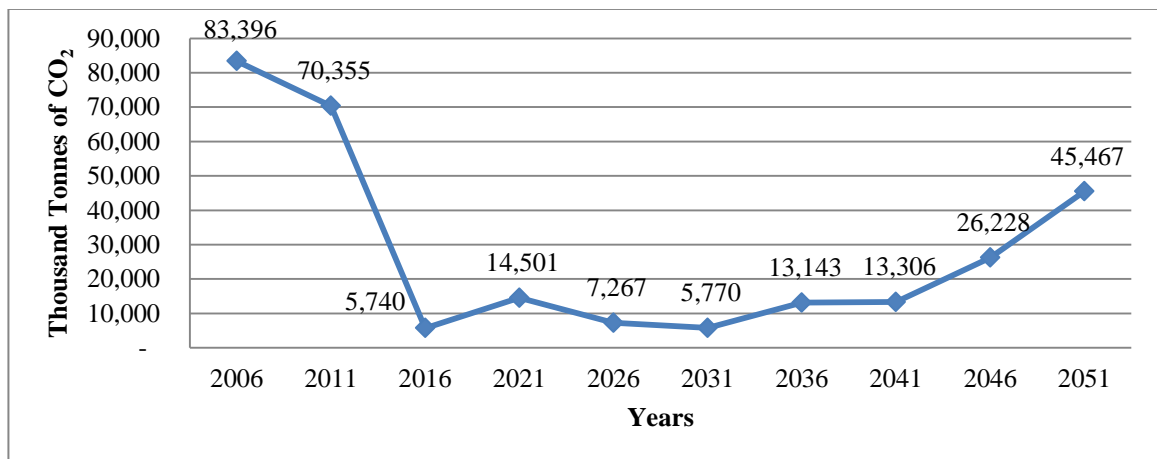


Figure 5.46. CO<sub>2</sub> Emissions of the electricity sector in the C4NFFP80 scenario.

40% emission reduction, utilization of nuclear power and high fuel prices has great favorable influences on CO<sub>2</sub> emissions. In 2031, coal reaches its minimum consumption level with 2.6% share and nuclear power reaches its maximum consumption with 64.3% share, which results in the one of lowest amount of CO<sub>2</sub> emissions.

When the results of this scenario are compared to the C\_40NUCF and the RS\_FP80 scenarios, this scenario is more beneficial for the environment. The electricity sector CO<sub>2</sub> emission decrease percentage (compared to the base scenario) is 93% in the C4NFFP80 scenario, while this reduction is 87% in the C\_40NUCF scenario and 9% in the RS\_FP80 scenario.

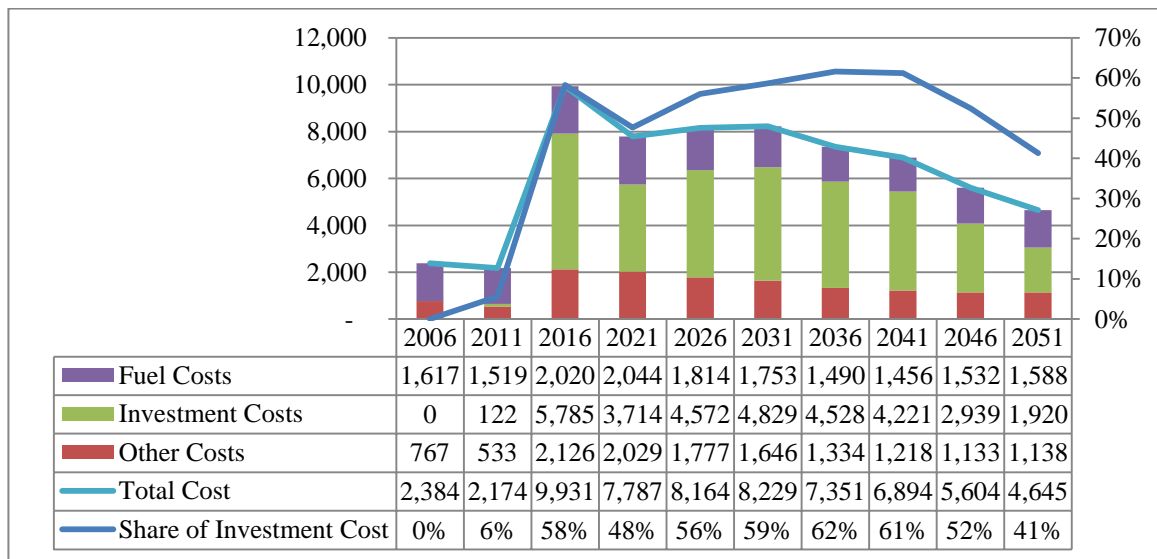


Figure 5.47. Costs of the electricity sector in the C4NFFP80 scenario (M pounds).

On the other hand, as can be inferred from Figure 5.47, all costs in the electricity sector are very much higher in this scenario compared to the costs in the base scenario. Especially, the increase in investment costs and total electricity sector costs are the most remarkable (this is because nuclear power generation and reducing CO<sub>2</sub> emission result in high investment costs).

### 5.2.16. The Nuclear, Emission Restriction, Fuel Price Increase and Emission Tax Scenario

In this scenario, which is named the C4NFF8T2 scenario, the fast nuclear scenario is integrated with the 40% emission reduction, the 80% fuel price increase and the 20 TL tax per tonne of CO<sub>2</sub> scenarios in order to measure the combined effects of nuclear energy, emission reduction enforcement, fuel price increase and taxes. For this scenario, energy

consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.51 and 5.52, respectively.

Table 5.51. Energy consumptions of the electricity sector by resources in the C4NFF8T2 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	3.0	4.5	5.1	2.6	0.9	0.0	0.0	0.0	0.0
COAL	571.3	314.0	44.8	143.0	154.7	82.9	894.5	892.4	2,119.7	4,009.0
DIESEL	3.7	3.9	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0
GEOHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	39.3	0.6	0.0	0.7	0.7	0.7	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	670.6	750.7	750.0	748.8	748.2	747.2	745.8	716.4
NATURAL GAS	493.8	735.0	29.1	23.7	3.6	2.8	1.5	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	141.9	185.2	201.9	265.3	305.1	341.5	377.7	417.6
NUCLEAR	0.0	0.0	169.9	431.0	1,124.0	2,018.7	2,018.7	3,429.9	3,663.2	3,663.2
ANNUAL TOTAL	1,328.0	1,303.8	1,076.5	1,555.8	2,254.6	3,137.7	3,984.1	5,424.6	6,918.2	8,816.1

Table 5.52. Share of energy consumptions in the electricity sector by resources in the C4NFF8T2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	24.1	4.2	9.2	6.9	2.6	22.5	16.5	30.6	45.5
DIESEL	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GEOHERMAL	0.1	0.8	1.5	1.0	0.8	0.6	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	16.8	62.3	48.3	33.3	23.9	18.8	13.8	10.8	8.1
NATURAL GAS	37.2	56.4	2.7	1.5	0.2	0.1	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.4	13.2	11.9	9.0	8.5	7.7	6.3	5.5	4.7
NUCLEAR	0.0	0.0	15.8	27.7	49.9	64.3	50.7	63.2	52.9	41.6
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

The energy consumptions in this scenario and the C4NFFP80 scenario are the same, which shows that additional 20 TL tax application does not have any effect.

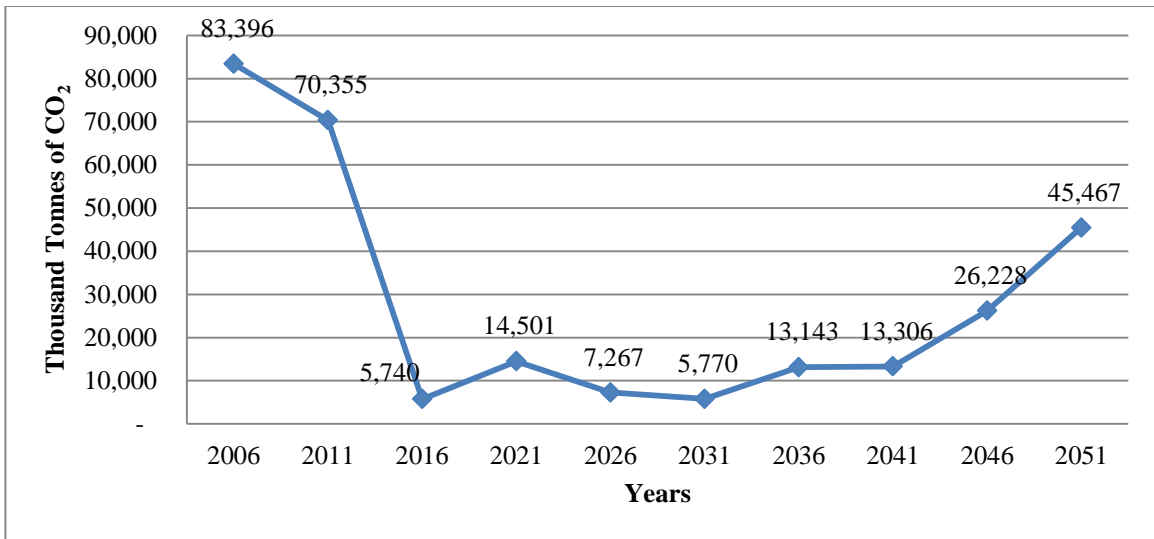


Figure 5.48. CO<sub>2</sub> Emissions of the electricity sector in the C4NFF8T2 scenario.

Likewise, the CO<sub>2</sub> emissions are the same as those in the C4NFFP80 scenario.

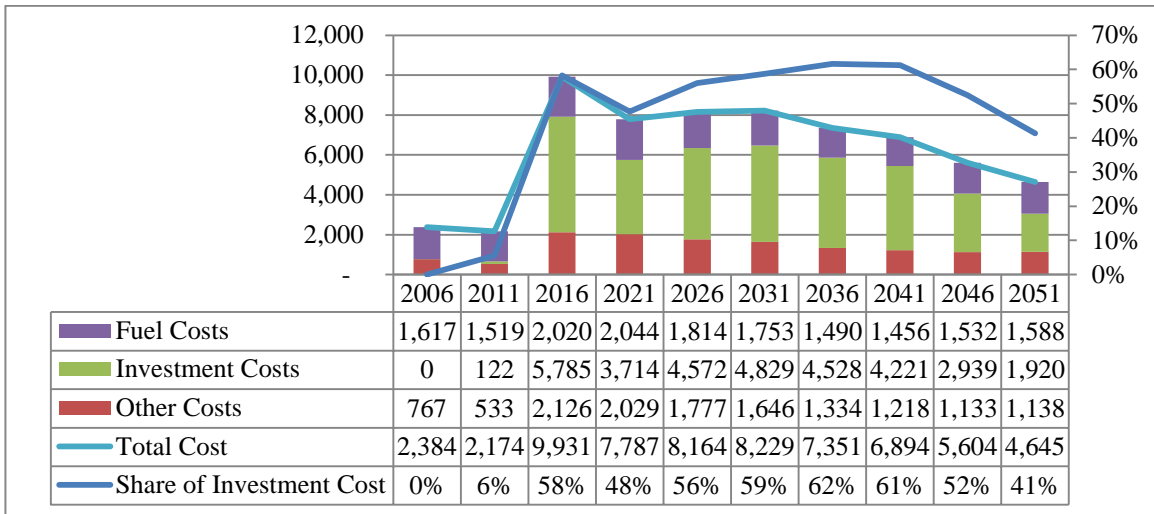


Figure 5.49. Costs of the electricity sector in the C4NFF8T2 scenario (M pounds).

The costs of this scenario are also the same as those in the C4NFFP80 scenario.

**5.2.17. The CCS and Tax Scenario**

In this scenario, which is named the CCSHT2 scenario, the high CCS scenario is integrated with the 20TL tax per tonne of CO<sub>2</sub> scenario in order to see their combined

influences on the electricity sector. For this scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.53 and 5.54, respectively.

Table 5.53. Energy consumptions of the electricity sector by resources in the CCSHT2 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	6.1	5.1	1.9	0.9	0.0	0.0	0.0	0.0
COAL	571.3	536.1	812.5	815.6	1,496.2	2,156.4	2,964.5	4,106.9	5,135.3	6,585.2
DIESEL	3.7	4.5	1.5	1.5	1.0	0.5	0.1	0.1	0.1	0.1
GEOHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	39.3	4.1	9.9	95.8	6.4	11.5	0.6	0.5	0.5	0.3
HYDRO	218.5	218.6	218.5	218.6	218.5	218.6	214.8	196.8	208.1	177.3
NATURAL GAS	493.8	735.0	470.3	765.1	708.8	719.5	669.5	669.7	927.7	1,118.8
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	72.0	92.1	89.0	106.4	113.5	88.4	82.3	84.6
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TOTAL	1,328.0	1,529.3	1,606.5	2,010.1	2,538.6	3,231.3	3,978.5	5,076.2	6,365.9	7,976.2

Table 5.54. Share of energy consumptions in the electricity sector by resources in the CCSHT2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	35.1	50.6	40.6	58.9	66.7	74.5	80.9	80.7	82.6
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOHERMAL	0.1	0.7	1.0	0.8	0.7	0.5	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	3.0	0.3	0.6	4.8	0.3	0.4	0.0	0.0	0.0	0.0
HYDRO	16.5	14.3	13.6	10.9	8.6	6.8	5.4	3.9	3.3	2.2
NATURAL GAS	37.2	48.1	29.3	38.1	27.9	22.3	16.8	13.2	14.6	14.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	4.5	4.6	3.5	3.3	2.9	1.7	1.3	1.1
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

In this scenario; wind, natural gas, geothermal and bio energy consumptions are increasing compared to the base scenario. Hydro energy consumption decreases towards to the end of the planning horizon, but it is still higher than that of the base scenario. Some fossil fuels such as diesel, and heavy fuel oil also have a decreasing consumption levels. Nuclear power generation is not used in this scenario.

When the results of this scenario are compared to the RS\_TAX20 and the RS\_CCSH scenarios, it can be seen that hydro and wind consumptions in this combined scenario are slightly higher. In addition, natural gas consumption in this combined scenario is higher than those in the RS\_TAX20 and the RS\_CCSH scenarios towards the end of the planning horizon. Coal consumption is lower than that of the RS\_CCSH scenario; however, it is higher than that of the RS\_TAX20 scenario (since CCS installation provides low CO<sub>2</sub> emissions even at high coal consumption levels).

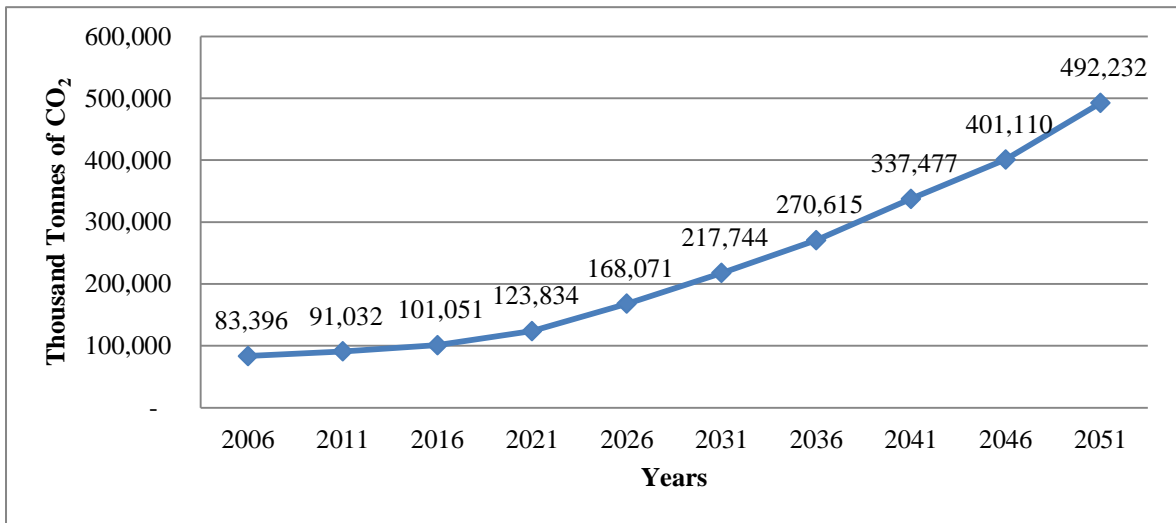


Figure 5.50. CO<sub>2</sub> Emissions of the electricity sector in the CCSHT2 scenario.

As it can be inferred from Figure 5.50, CO<sub>2</sub> emissions display a similar increasing trend observed in many other scenarios. When the results of CCSHT2, RS\_CCSH and RS\_TAX20 scenarios are compared, it is seen that, the electricity sector CO<sub>2</sub> emission decrease percentage (compared to the base scenario) is 29% in the CCSHT2 scenario and 5% in the RS\_TAX20 scenario. Also, CO<sub>2</sub> emissions in the RS\_CCSH are higher than those in the CCSHT2 and the RS\_TAX20 scenarios. This shows that the combined scenario is relatively clean compared to the RS\_TAX20 and the RS\_CCSH scenarios.

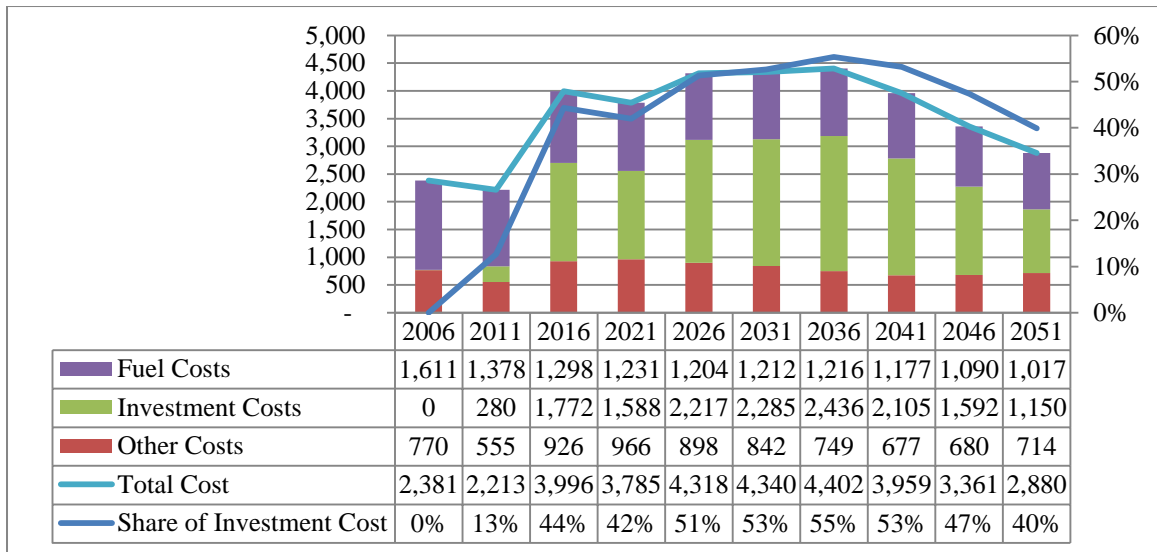


Figure 5.51. Costs of the electricity sector in the CCSHT2 scenario (M pounds).

As shown in Figure 5.51, since installation of CCS technologies result in high investment costs, the investment costs in this scenario have a sharp increase in the period 2016 which continues in later periods. Fuel costs, on the other hand, decreases from 2011 onwards. Increase in total electricity sector costs is not much compared to the RS\_CCSH scenario.

### 5.2.18. The CCS and Fuel Price Increase Scenario

In this scenario, which is named the CCSHFP80 scenario, the high CCS scenario is integrated with the fuel price increase scenario in order to see their combined influences on the electricity sector. For this scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.55 and 5.56, respectively.

Table 5.55. Energy consumptions of the electricity sector by resources in the CCSHFP80 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.1	5.7	2.9	1.8	0.9	0.0	0.0	0.0
COAL	571.3	536.1	1,165.5	1,160.3	1,700.7	2,302.3	3,044.0	4,066.2	5,557.9	7,217.9
DIESEL	3.7	4.5	1.7	1.7	0.4	0.2	0.1	0.0	0.0	0.0
GEOTHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	39.3	4.1	9.9	9.9	2.3	1.1	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	348.4	447.9	446.5	446.6	445.6	444.3	442.9	413.5
NATURAL GAS	493.8	735.0	82.8	89.8	27.9	27.8	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	72.0	185.2	187.6	218.7	235.3	248.3	168.1	184.7
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TOTAL	1,328.0	1,529.3	1,701.1	1,916.8	2,385.1	3,015.8	3,741.8	4,772.5	6,180.7	7,826.0

Table 5.56. Share of energy consumptions in the electricity sector by resources in the CCSHFP80 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0
COAL	43.0	35.1	68.5	60.5	71.3	76.3	81.4	85.2	89.9	92.2
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.7	0.9	0.9	0.7	0.6	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	3.0	0.3	0.6	0.5	0.1	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	14.3	20.5	23.4	18.7	14.8	11.9	9.3	7.2	5.3
NATURAL GAS	37.2	48.1	4.9	4.7	1.2	0.9	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	4.2	9.7	7.9	7.3	6.3	5.2	2.7	2.4
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

In this scenario; the consumptions of fossil fuels such as diesel, heavy fuel oil, and natural gas are decreasing over the planning horizon. It should be noted that natural gas is not consumed beyond 2036. Also, coal consumption is lower than that of the base scenario, but the change in coal consumption is not large because CCS technologies provide utilization of coal with less CO<sub>2</sub> emissions.

Furthermore, geothermal, wind and bio energy consumptions are higher than those in the base scenario and hydro energy consumption rises from 1.6 % to 5.3% at the end of the planning horizon compared to the base scenario.

When the results of the CCSHFP80 scenario are compared to the RS\_FP80 scenario, it can be observed that coal and geothermal consumptions in this combined scenario are higher. Wind energy consumption is also higher than those in the RS\_CCSH and RS\_FP80 scenarios towards the end of the planning horizon. Natural gas consumption in this combined scenario is lower than those in the RS\_FP80 and the RS\_CCSH scenarios. However, hydro consumption in this combined scenario is lower than those in the RS\_FP80 scenario, but higher than those in the RS\_CCSH scenario. In other words, increased fuel prices together with high CCS investments result in increased coal, wind and geothermal consumptions; and less hydro, natural gas, diesel and fuel oil (whose import prices are increased) consumptions.

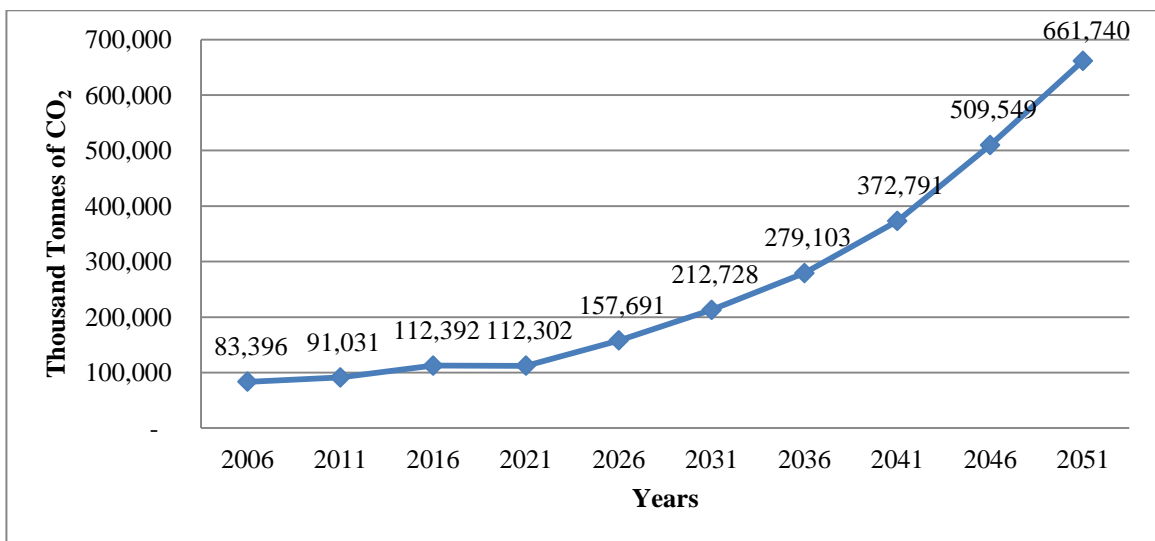


Figure 5.52. CO<sub>2</sub> Emissions of the electricity sector in the CCSHFP80 scenario.

As depicted in Figure 5.51, while CO<sub>2</sub> emissions are continuously increasing period by period, they are lower than those in the base scenario. Also, CO<sub>2</sub> emissions in the CCSHT2 scenario are lower than those in the CCSHFP80 scenario. Therefore, it can be concluded that CCSHT2 scenario is more effective than CCHFP80 in terms of reducing CO<sub>2</sub> emissions. Electricity sector CO<sub>2</sub> emission reduction is 9% (compared to those in the

base scenario) in the RS\_FP80 scenario, but it is 5% in the CCSHFP80 scenario, at the end of the planning horizon.

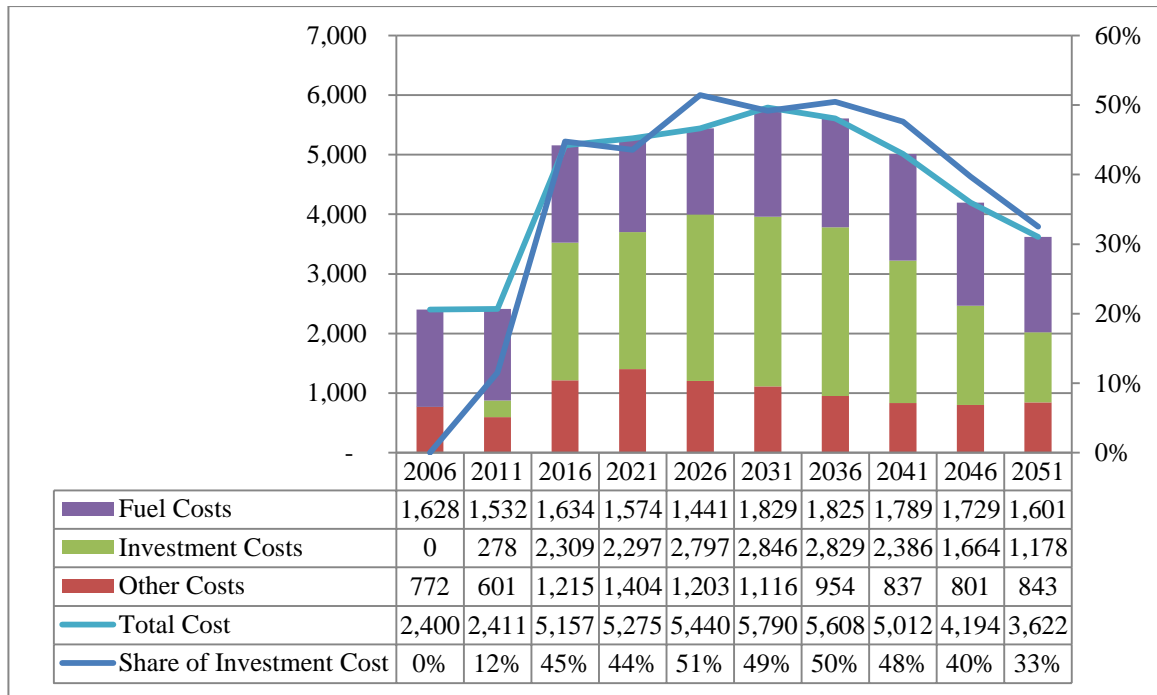


Figure 5.53. Costs of the electricity sector in the CCSHFP80 scenario (M pounds).

As it is depicted in Figure 5.52, with CCS technologies, the investment cost is sharply increasing in 2016. The investment costs in this combined scenario are higher than those in the RS\_CCSH scenario over the planning horizon. Moreover, as Turkey is mostly using fossil energy carriers such as oil and coal, higher fuel prices of these fossil fuels result in higher fuel costs. However, fuel costs in the CCSHFP80 scenario are lower than those in the RS\_FP80 scenario.

### 5.2.19. The CCS, Fuel Price Increase and Tax Scenario

In this scenario, which is named the CHFP80T2 scenario, the high CCS scenario is integrated with the 80% fuel price increase and the 20TL tax per ton of CO<sub>2</sub> scenarios in order to see their combined influences on the electricity sector. For this scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.57 and 5.58, respectively.

Table 5.57. Energy consumptions of the electricity sector by resources in the CHFP80T2 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.1	5.7	3.6	2.6	0.9	0.0	0.0	0.0
COAL	571.3	536.1	812.5	850.4	1,374.3	1,572.5	2,328.1	3,299.9	4,794.3	6,448.5
DIESEL	3.7	4.5	1.6	1.7	0.4	0.2	0.1	0.0	0.0	0.0
GEOTHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	39.3	4.1	9.9	9.9	2.3	1.1	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	458.2	532.4	531.7	531.0	530.3	528.7	527.3	505.5
NATURAL GAS	493.8	735.0	86.1	92.1	31.1	31.4	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	72.0	185.2	192.4	265.3	305.1	341.5	261.3	277.8
NUCLEAR	0.0	0.0	0.0	0.0	0.0	433.1	433.1	433.1	433.1	433.1
ANNUAL TOTAL	1,328.0	1,529.3	1,461.1	1,693.6	2,152.7	2,854.5	3,613.5	4,616.9	6,027.8	7,674.9

Table 5.58. Share of energy consumptions in the electricity sector by resources in the CHFP80T2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.4	0.3	0.2	0.1	0.0	0.0	0.0	0.0
COAL	43.0	35.1	55.6	50.2	63.8	55.1	64.4	71.5	79.5	84.0
DIESEL	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.7	1.1	1.0	0.8	0.6	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	3.0	0.3	0.7	0.6	0.1	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	14.3	31.4	31.4	24.7	18.6	14.7	11.5	8.7	6.6
NATURAL GAS	37.2	48.1	5.9	5.4	1.4	1.1	0.0	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.2	4.9	10.9	8.9	9.3	8.4	7.4	4.3	3.6
NUCLEAR	0.0	0.0	0.0	0.0	0.0	15.2	12.0	9.4	7.2	5.6
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

When this scenario is compared to the CCSHFP80 scenario, it can be seen that hydro, wind and bio energy consumptions are higher while coal, diesel and natural gas consumptions are lower. Geothermal and heavy fuel oil consumptions remain nearly the same. Moreover, nuclear energy is used beyond 2031. So it can be concluded that, when the CCSHFP80 scenario is combined with the RS\_TAX20 scenario; the model prefers to use more renewables and less fossil fuels.

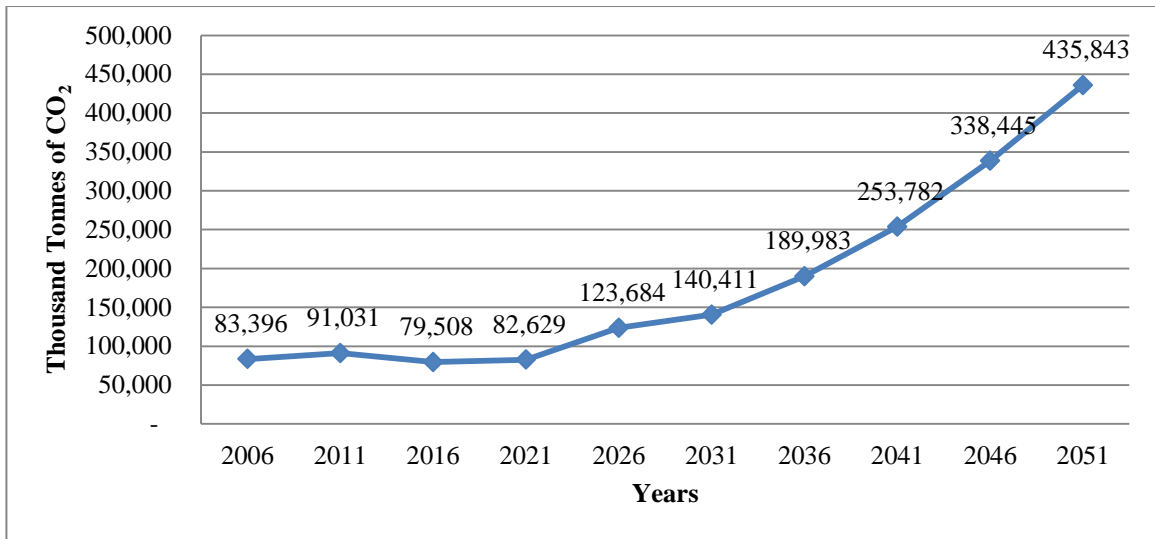


Figure 5.54. CO<sub>2</sub> Emissions of the electricity sector in the CHFP80T2 scenario.

When emission results of the CHFP80T2 and CCSHFP80 scenarios are investigated, it can be seen that CO<sub>2</sub> emissions drop more once the 20 TL tax is applied to per tonne of CO<sub>2</sub> emissions, compared to the CCSHFP80 scenario. This is mostly due to the deployment of nuclear power and decreased coal consumptions.

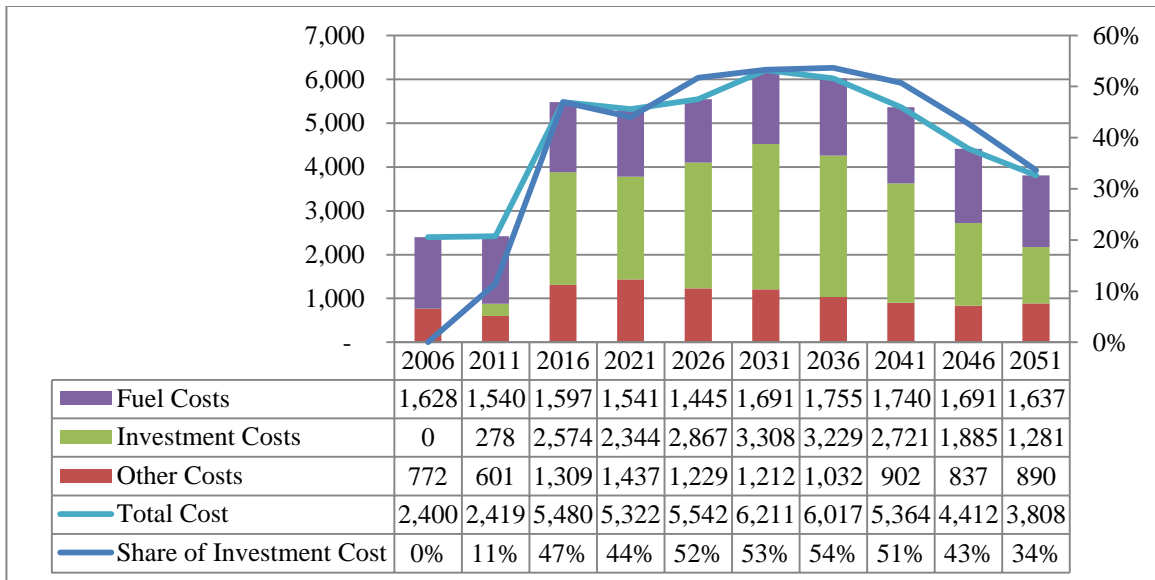


Figure 5.55. Costs of the electricity sector in the CHFP80T2 scenario (M pounds).

As it can be inferred from Figure 5.55, similar to the CCSHFP80 scenario, there is a sharp increase in the investments costs in 2016. The investment costs in this scenario are



Geothermal, hydro, wind, and bio energy consumptions in this scenario are higher than those in the RS\_CCSH scenario. Moreover, heavy fuel oil and diesel are not consumed anymore beyond 2016. Although, coal consumption sharply decreases in 2016 (in the C\_40CCSH scenario), it is rebounds beyond 2012. It must be mentioned that the energy consumptions in the C\_40CCSH scenario are nearly the same as those in the RS\_C\_40 scenario.

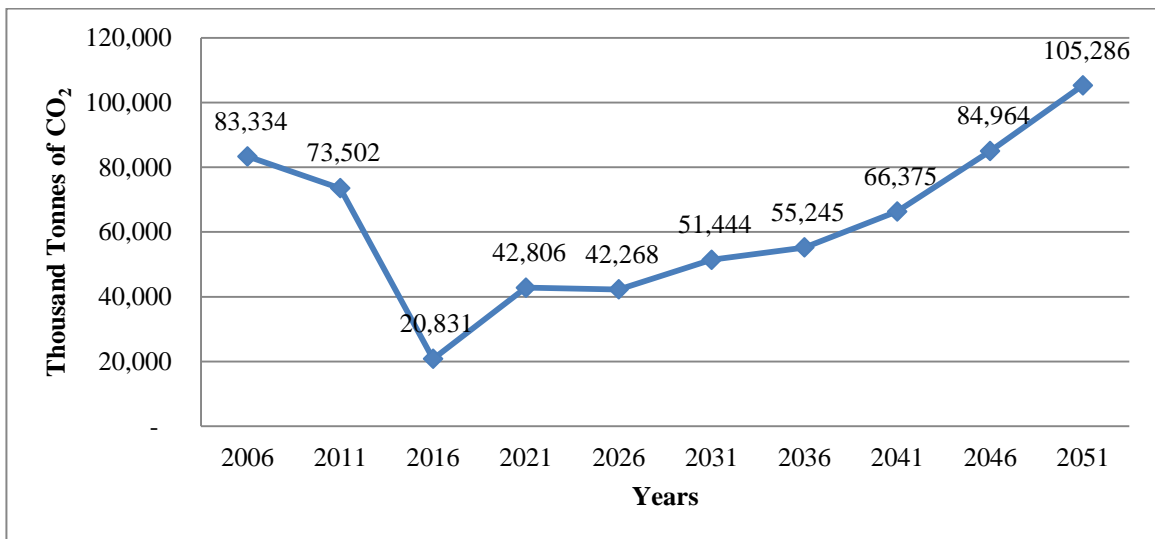


Figure 5.56. CO<sub>2</sub> Emissions of the electricity sector in the C\_40CCSH scenario.

When Figure 5.56 is analyzed, emission reduction by 40% with usage of CCS technologies result in remarkable drop in the CO<sub>2</sub> emissions of the electricity generation sector. However, there is not a remarkable difference between CO<sub>2</sub> emission in the C\_40CCSH, the RS\_C\_40 (whose CO<sub>2</sub> emission decrease percentage is 85% compared to the base scenario) and the C\_40CCSH (whose CO<sub>2</sub> emission decrease percentage is 85% compared to the base scenario) scenarios at the end of the planning horizon.

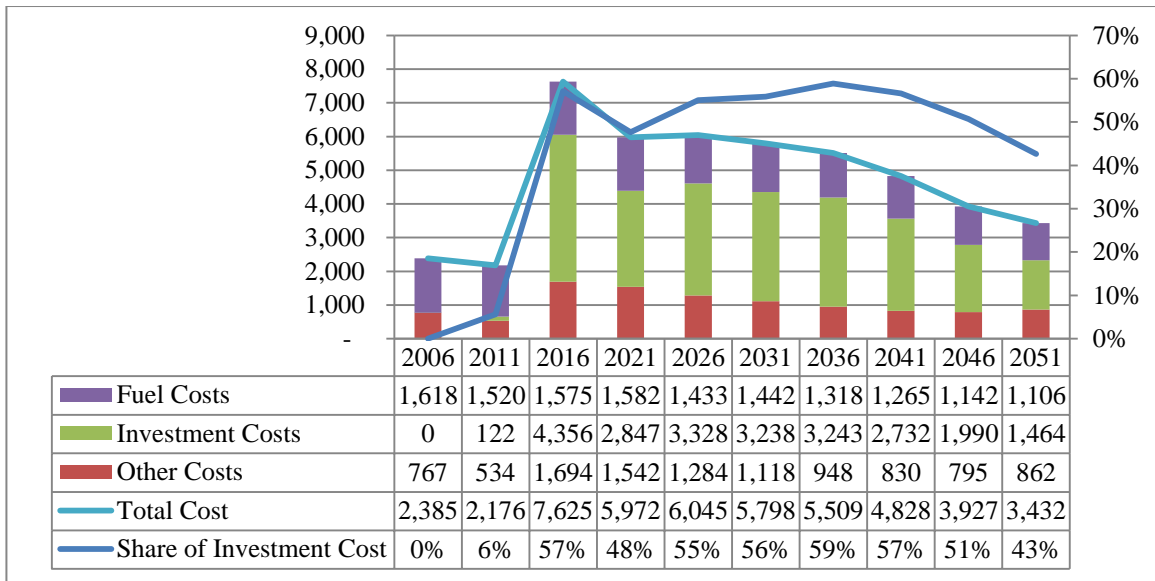


Figure 5.57. Costs of the electricity sector in the C\_40CCSH scenario (M pounds).

As it can be inferred from Figure 5.57, the investment costs sharply increases beyond 2016 (which is the period that CCS enforcement starts). Another reason of these high investment costs is the installation of new technologies to reduce CO<sub>2</sub> emissions immediately. Additionally, the fuel and investment costs of this scenario are higher than those in the RS\_CCSH scenario. Moreover, it is worth mentioning that the cost results of this combined scenario is almost the same as those of the RS\_C\_40 scenario.

### 5.2.21. The CCS, Emission Restriction and Tax Scenario

In this scenario, which is named the C4CCSHT2 scenario, the high CCS scenario is integrated with the 40% emission reduction and the 20TL tax per ton of CO<sub>2</sub> scenarios in order to see their combined influences on the electricity sector. For this scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.61 and 5.62, respectively.

Table 5.61. Energy consumptions of the electricity sector by resources in the C4CCSHT2 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	2.4	5.8	6.0	2.6	0.9	0.0	0.0	0.0	0.0
COAL	571.3	348.1	0.4	17.5	751.2	1,510.4	2,611.0	3,956.6	5,285.4	7,365.6
DIESEL	4.6	3.9	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1
GEOTHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	38.4	0.8	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	531.9	532.4	532.2	531.6	506.7	498.7	492.4	451.3
NATURAL GAS	492.8	735.0	371.3	735.0	630.7	636.6	514.8	536.6	650.6	672.9
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	141.9	185.2	187.6	218.7	235.3	178.4	168.1	184.7
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TOTAL	1,326.9	1,337.5	1,066.9	1,492.4	2,121.1	2,915.6	3,883.9	5,183.9	6,608.4	8,684.5

Table 5.62. Share of energy consumptions in the electricity sector by resources in the C4CCSHT2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.5	0.4	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.1	26.0	0.0	1.2	35.4	51.8	67.2	76.3	80.0	84.8
DIESEL	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.8	1.5	1.1	0.8	0.6	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	2.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	16.3	49.9	35.7	25.1	18.2	13.0	9.6	7.5	5.2
NATURAL GAS	37.1	55.0	34.8	49.3	29.7	21.8	13.3	10.4	9.8	7.7
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.4	13.3	12.4	8.8	7.5	6.1	3.4	2.5	2.1
NUCLEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

The energy consumptions in this scenario and the C\_40CCSH scenario are the same, which shows that additional 20 TL tax application does not have any effect.

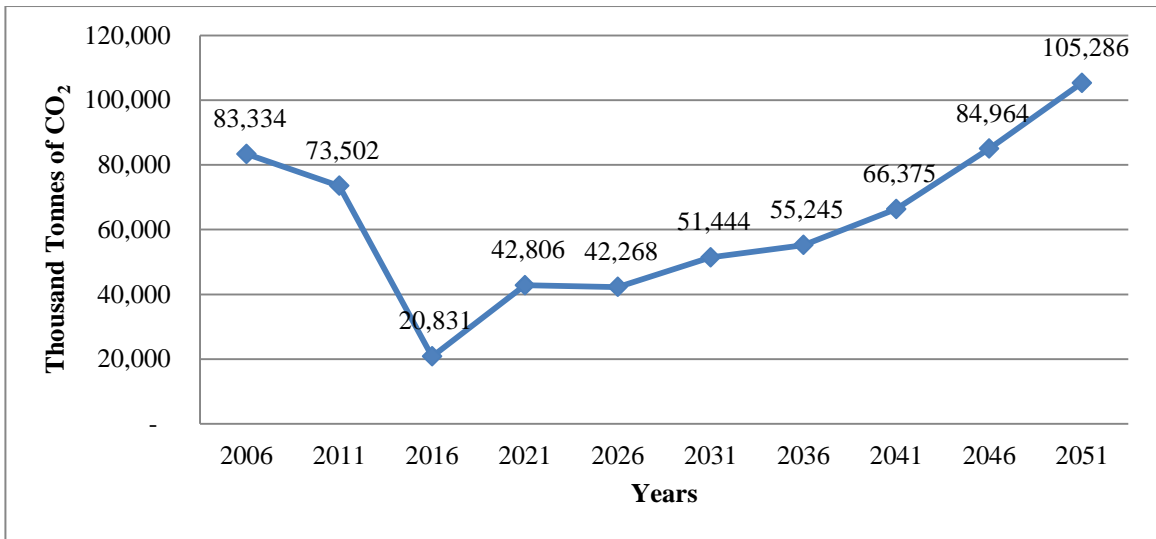


Figure 5.58. CO<sub>2</sub> Emissions of the electricity sector in the C4CCSHT2 scenario.

Likewise, the CO<sub>2</sub> emissions in the C4CCSHT2 scenario are the same as those in the C\_40CCSH scenario.

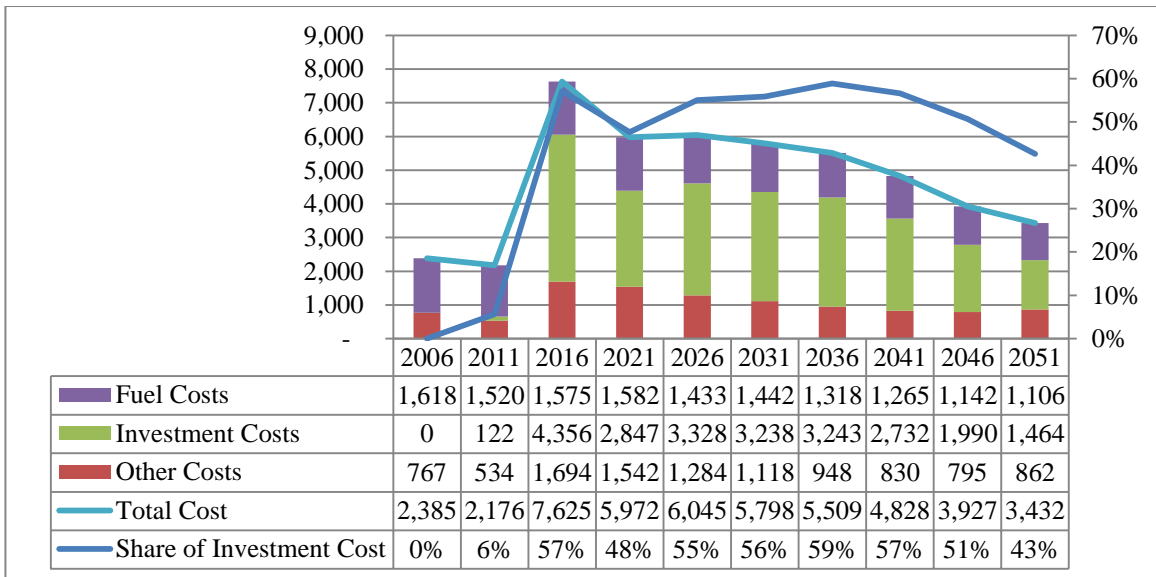


Figure 5.59. Costs of the electricity sector in the C4CCSHT2 scenario (M pounds).

Also, the costs of the C4CCSHT2 scenario are the same as those in the C\_40CCSH scenario.

### 5.2.22. The CCS, Emission Restriction and Fuel Price Increase Scenario

In this scenario, which is named the C4CHFP80 scenario, the high CCS scenario is integrated with the 40% emission reduction and the 80% fuel price increase scenarios in order see their combined effects on the electricity sector. For this scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.63 and 5.64, respectively.

Table 5.63. Energy consumptions of the electricity sector by resources in the C4CHFP80 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	3.0	4.5	5.7	1.9	0.9	0.0	0.0	0.0	0.0
COAL	571.3	314.0	68.3	319.7	141.5	82.0	926.8	925.3	2,333.2	4,228.8
DIESEL	3.7	3.9	0.0	0.3	0.1	0.1	0.1	0.0	0.0	0.0
GEOTHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	39.3	0.6	0.0	1.7	0.7	0.7	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	718.1	756.7	755.9	754.5	754.0	753.0	751.6	722.2
NATURAL GAS	493.8	735.0	29.1	24.2	4.1	2.7	2.7	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	141.9	185.2	201.9	265.3	305.1	341.5	377.7	417.6
NUCLEAR	0.0	0.0	0.0	180.4	1,135.4	1,949.4	1,949.4	3,361.9	3,361.9	3,361.9
ANNUAL TOTAL	1,328.0	1,303.8	977.7	1,490.1	2,258.4	3,073.1	3,954.1	5,395.5	6,836.3	8,740.5

Table 5.64. Share of energy consumptions in the electricity sector by resources in the C4CHFP80 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.5	0.4	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	24.1	7.0	21.5	6.3	2.7	23.4	17.2	34.1	48.4
DIESEL	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GEOTHERMAL	0.1	0.8	1.6	1.1	0.7	0.6	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	3.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	16.8	73.5	50.8	33.5	24.6	19.1	14.0	11.0	8.3
NATURAL GAS	37.2	56.4	3.0	1.6	0.2	0.1	0.1	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.4	14.5	12.4	8.9	8.6	7.7	6.3	5.5	4.8
NUCLEAR	0.0	0.0	0.0	12.1	50.3	63.4	49.3	62.3	49.2	38.5
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

Diesel and heavy fuel oil consumptions in the C4CHFP80 scenario decrease over the planning horizon. Natural gas, which is one of the important energy sources in Turkey, is also sharply decreasing over the planning horizon. When the C4CHFP80 scenario is

compared to the C\_40CCSH scenario, the coal consumption in the C4CHFP80 scenario is nearly equal to half of the coal consumption in the C\_40CCSH scenario. On the other hand, hydro and wind energy consumptions in the C4CHFP80 scenario are higher than those in the C\_40CCSH scenario. As can be inferred from these results, the model prefer to utilize more hydro and wind energy resources (which have less fuel prices) and less coal and natural gas because of the increased fuel prices. Apart from them, nuclear power is used in the C4CHFP80 scenario beyond 2021 which results from the combined effects of fuel price increase scenario and the C\_40CCSH scenario.

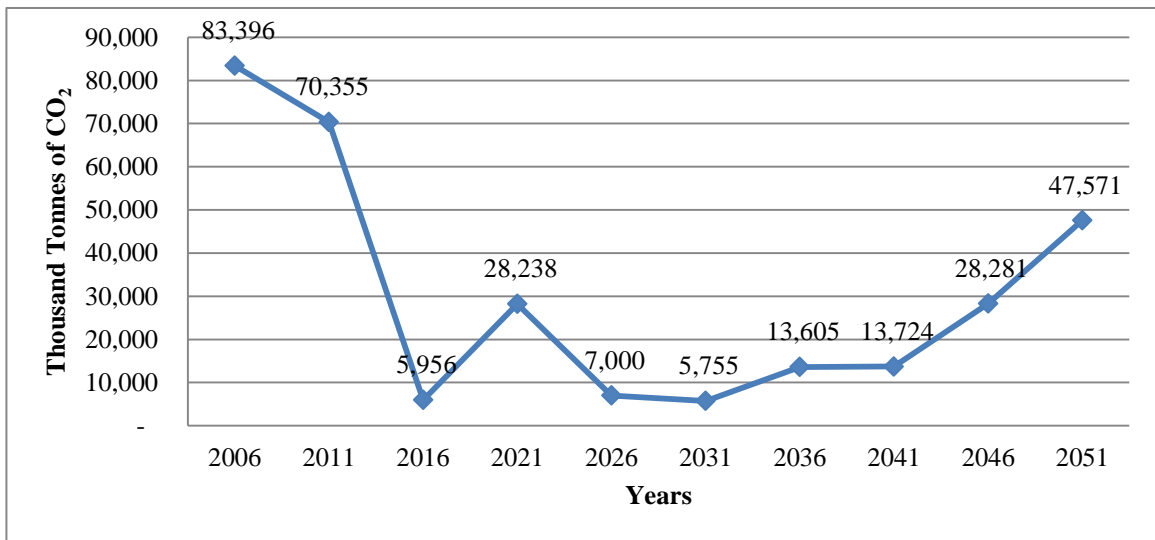


Figure 5.60. CO<sub>2</sub> Emissions of the electricity sector in the C4CHFP80 scenario.

When the results are investigated, it is observed that there is a sharp increase in electricity sector CO<sub>2</sub> emissions in 2021 which is mostly caused by increased coal consumption in that year. The CO<sub>2</sub> emissions in 2051 are almost half of the CO<sub>2</sub> emissions in 2006. Therefore, it indicates that emission reduction by 40%, high CCS and fuel price change has great effects on CO<sub>2</sub> emissions. The decrease percentage of electricity sector CO<sub>2</sub> emissions (compared to the base scenario) is 85% in the C\_40CCSH scenario and 93% in the C4CHFP80 scenario.

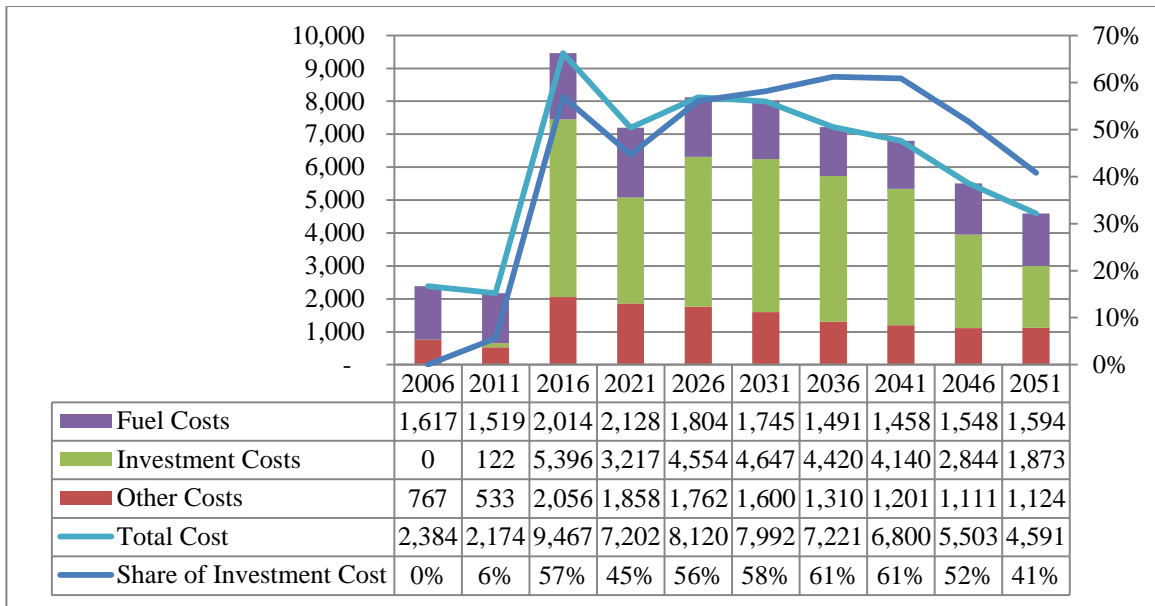


Figure 5.61. Costs of the electricity sector in the C4CHFP80 scenario (M pounds).

As can be seen in Figure 5.61, there is a sharp increase in the investment costs in 2016 compared to the other scenarios (such as the RS\_FP80 and the C\_40CCSH scenarios) since fuel consumption shifts from fossil fuels to renewables that require new investments. Besides, fuel costs in this scenario are also higher than those in the C\_40CCSH scenario because of the impacts of increased fuel prices.

### 5.2.23. The CCS, Fuel Price Increase, Emission Restriction and Tax Scenario

In this scenario, which is named the C4CHF8T2 scenario, the high CCS scenario is integrated with the 40% emission reduction, 80% fuel price increase and 20 TL tax per tonne of CO<sub>2</sub> scenarios, in order to see their combined influences on the electricity sector. For this scenario, energy consumptions by resources and share of these resources for the electricity sector are displayed in Tables 5.65 and 5.66, respectively.

Table 5.65. Energy consumptions of the electricity sector by resources in the C4CHF8T2 scenario (PJ).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	3.0	4.5	5.7	1.9	0.9	0.0	0.0	0.0	0.0
COAL	571.3	314.0	68.3	319.7	141.5	82.0	926.8	925.3	2,333.2	4,228.8
DIESEL	3.7	3.9	0.0	0.3	0.1	0.1	0.1	0.0	0.0	0.0
GEOHERMAL	1.3	10.1	15.7	16.3	16.9	17.5	15.6	13.7	11.8	9.9
HEAVY FUEL OIL	39.3	0.6	0.0	1.7	0.7	0.7	0.4	0.0	0.0	0.0
HYDRO	218.5	218.6	718.1	756.7	755.9	754.5	754.0	753.0	751.6	722.2
NATURAL GAS	493.8	735.0	29.1	24.2	4.1	2.7	2.7	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	18.7	141.9	185.2	201.9	265.3	305.1	341.5	377.7	417.6
NUCLEAR	0.0	0.0	0.0	180.4	1,135.4	1,949.4	1,949.4	3,361.9	3,361.9	3,361.9
ANNUAL TOTAL	1,328.0	1,303.8	977.7	1,490.1	2,258.4	3,073.1	3,954.1	5,395.5	6,836.3	8,740.5

Table 5.66. Share of energy consumptions in the electricity sector by resources in the C4CHF8T2 scenario (%).

ENERGY	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
BIO ENERGY	0.0	0.2	0.5	0.4	0.1	0.0	0.0	0.0	0.0	0.0
COAL	43.0	24.1	7.0	21.5	6.3	2.7	23.4	17.2	34.1	48.4
DIESEL	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GEOHERMAL	0.1	0.8	1.6	1.1	0.7	0.6	0.4	0.3	0.2	0.1
HEAVY FUEL OIL	3.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
HYDRO	16.5	16.8	73.5	50.8	33.5	24.6	19.1	14.0	11.0	8.3
NATURAL GAS	37.2	56.4	3.0	1.6	0.2	0.1	0.1	0.0	0.0	0.0
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	0.0	1.4	14.5	12.4	8.9	8.6	7.7	6.3	5.5	4.8
NUCLEAR	0.0	0.0	0.0	12.1	50.3	63.4	49.3	62.3	49.2	38.5
TOTAL PERCENTAGE	100	100	100	100	100	100	100	100	100	100

The energy consumptions in this scenario and the C4CHFP80 scenario are the same, which shows that additional 20 TL tax application does not have any effect.

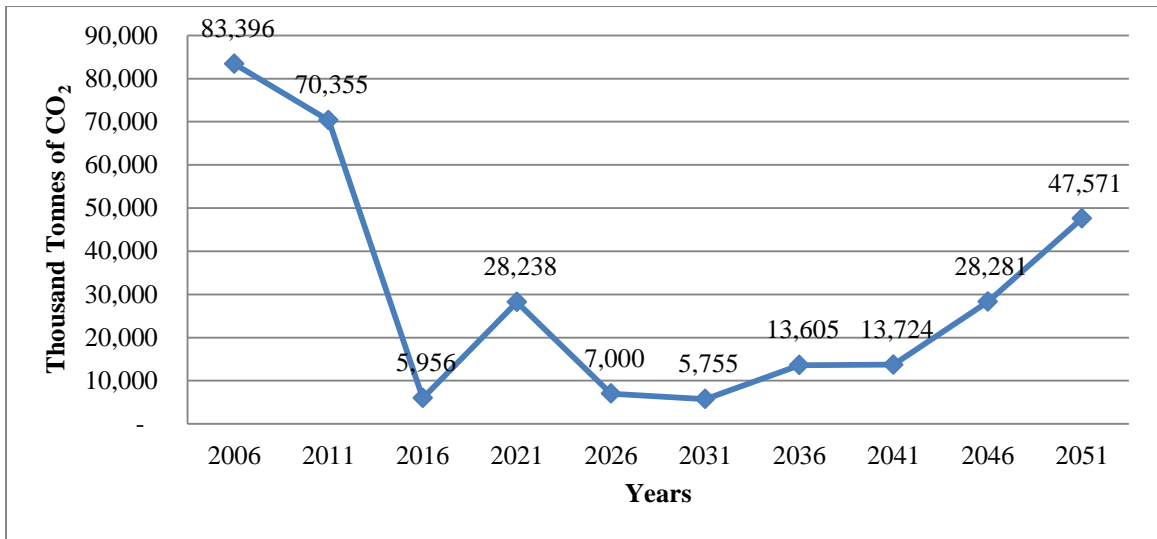


Figure 5.62. CO<sub>2</sub> Emissions of the electricity sector in the C4CHF8T2 scenario.

Similar to energy consumptions, the CO<sub>2</sub> emissions are the same as those in the C4CHFP80 scenario.

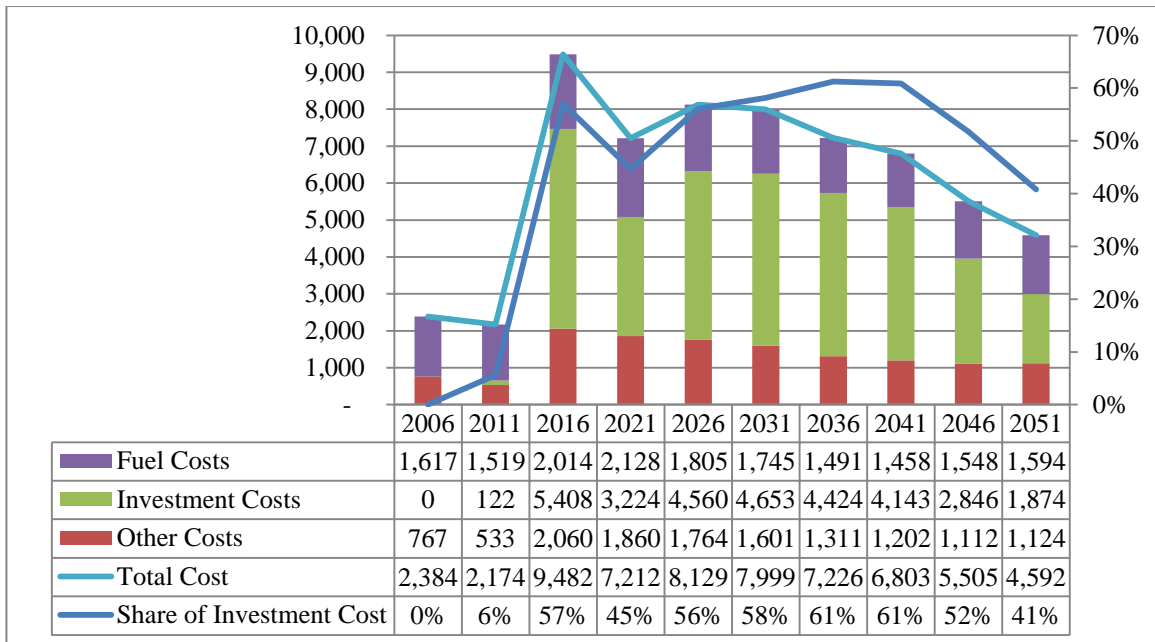


Figure 5.63. Costs of the electricity sector in the C4FP80T2 scenario (M pounds).

Besides, the costs of this scenario are nearly the same as those in the C4CHFP80 scenario.

## 6. CONCLUSION

This section features an overview of the scenario analysis accomplished and results obtained in the previous section. The total system costs and the periodic GHG emissions (of the electricity sector) and the associated GHG savings per pound related with each scenario are displayed in Table 6.1 and 6.2.

Table 6.1. The CO<sub>2</sub> emissions of the electricity sector by scenarios (kt).

	SCENARIOS	TOTAL ELECTRICITY SECTOR CO <sub>2</sub> EMISSIONS	ELECTRICITY SECTOR CO <sub>2</sub> EMISSION SAVINGS	CO <sub>2</sub> EMISSIONS IN EACH PERIOD									
				2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
1	BASE	14,308,605		83,396	92,536	104,658	129,796	190,656	253,443	325,956	432,319	553,197	695,765
2	C_40CCSH	3,130,283	11,178,322	83,334	73,502	20,831	42,806	42,268	51,444	55,245	66,375	84,964	105,286
3	C_40FP80	1,519,306	12,789,299	83,396	70,355	5,956	28,238	7,000	5,755	13,602	13,721	28,275	47,561
4	C_40NUCF	2,708,370	11,600,235	83,334	73,591	18,060	32,780	33,307	39,713	43,561	53,246	75,682	88,399
5	C_40TAX2	3,135,398	11,173,207	83,334	73,502	20,957	43,249	42,422	51,540	55,294	66,530	84,965	105,286
6	C4CCSHT2	3,130,283	11,178,322	83,334	73,502	20,831	42,806	42,268	51,444	55,245	66,375	84,964	105,286
7	C4CHF8T2	1,519,412	12,789,193	83,396	70,355	5,956	28,238	7,000	5,755	13,605	13,724	28,281	47,571
8	C4CHFP80	1,519,412	12,789,193	83,396	70,355	5,956	28,238	7,000	5,755	13,605	13,724	28,281	47,571
9	C4FP80T2	1,519,306	12,789,299	83,396	70,355	5,956	28,238	7,000	5,755	13,602	13,721	28,275	47,561
10	C4NFF8T2	1,425,868	12,882,737	83,396	70,355	5,740	14,501	7,267	5,770	13,143	13,306	26,228	45,467
11	C4NFFP80	1,425,868	12,882,737	83,396	70,355	5,740	14,501	7,267	5,770	13,143	13,306	26,228	45,467
12	C4NFT2	2,708,370	11,600,235	83,334	73,591	18,060	32,780	33,307	39,713	43,561	53,246	75,682	88,399
13	CCSHFP80	12,963,616	1,344,989	83,396	91,031	112,392	112,302	157,691	212,728	279,103	372,791	509,549	661,740
14	CCSHT2	11,432,806	2,875,799	83,396	91,032	101,051	123,834	168,071	217,744	270,615	337,477	401,110	492,232
15	CHFP80T2	9,093,565	5,215,040	83,396	91,031	79,508	82,629	123,684	140,411	189,983	253,782	338,445	435,843
16	FP80TAX2	10,844,927	3,463,678	83,396	91,031	80,333	80,933	124,651	150,730	221,977	310,715	440,281	584,938
17	NFP80T2	7,801,833	6,506,772	83,396	91,031	72,458	72,256	101,740	76,470	143,649	222,140	306,447	390,779
18	NUCFP80	9,204,380	5,104,225	83,396	91,031	92,407	92,288	124,515	137,949	198,343	253,532	340,809	426,605
19	NUCFAX2	10,234,292	4,074,313	83,396	91,061	95,465	111,055	151,091	191,855	230,795	295,800	360,387	435,953
20	RS_C_20	8,586,609	5,721,996	83,334	91,149	76,487	90,896	114,622	138,608	186,773	248,941	334,126	352,384

Table 6.2. The CO<sub>2</sub> emissions of the electricity sector by scenarios (kt) (cont.).

21	RS_C_40	3,135,398	11,173,207	83,334	73,502	20,957	43,249	42,422	51,540	55,294	66,530	84,965	105,286
22	RS_CCESH	14,668,273	-359,668	83,396	92,653	120,317	143,000	201,447	264,822	336,097	438,174	555,344	698,406
23	RS_CCSL	14,505,596	-196,991	83,396	92,653	112,361	137,489	198,057	260,700	330,861	434,945	557,879	692,779
24	RS_FP40	14,742,594	-433,989	83,396	91,031	127,139	146,758	202,148	258,590	335,259	440,161	558,350	705,687
25	RS_FP80	12,160,327	2,148,278	83,396	91,031	92,083	91,901	142,443	193,018	264,973	354,921	486,430	631,869
26	RS_NUCF	10,817,858	3,490,747	83,396	92,653	101,379	116,720	160,734	203,497	250,285	314,251	382,521	458,135
27	RS_NUCS	13,614,538	694,067	83,396	91,102	102,694	125,123	179,861	237,684	305,783	403,934	524,852	668,479
28	RS_TAX10	13,701,637	606,968	83,396	91,032	101,591	125,333	181,606	242,263	310,130	414,222	526,246	664,508
29	RS_TAX20	13,513,444	795,161	83,396	91,032	101,205	124,640	176,012	235,709	304,452	407,955	519,477	658,809
30	RS_TAX40	9,310,365	4,998,240	83,396	91,082	92,689	111,912	95,517	100,327	166,624	255,137	366,344	499,045

Table 6.2 displays the total electricity sector costs for each scenario and the associated cost increases, compared to the electricity sector cost of the base scenario. When Tables 6.2 and 6.3 are analyzed, except for the RS\_CCSL scenario, the total electricity sector costs of all scenarios are higher than those in the base scenario. Since the total electricity sector cost of the RS\_CCSL scenario is lower than that of the base scenario, it is one of the most desirable scenarios in terms of both overall electricity sector costs and emissions.

The most costly group of scenarios is the 40% emission restriction scenario and its variants, since enforcement of 40% reduction in total CO<sub>2</sub> emissions requires new investments and utilization of high cost clean energy alternatives. Since the dominant fuel type in Turkey's energy sector is coal, which is the cheapest alternative but the greatest contributor of the CO<sub>2</sub> emissions; shifting from coal to clean energy types result in high costs.

Then, the nuclear energy based scenarios constitute the second group of high cost scenarios. The underlying reason of this is high installation costs of nuclear energy. Therefore, this group of scenarios gives significant clues to energy policy makers about Turkey's energy future.

Furthermore, fuel price increase scenarios and their variants have high costs because Turkey is highly dependent on imported energy. The results of this group of scenarios show that if fuel prices of imported energy increase, then Turkey's electricity costs will be highly and immediately effected.

As the amount of electricity sector cost increases get lower and the amount of electricity CO<sub>2</sub> emission savings get higher, the most favored scenarios are obtained. That is to say, the most preferable scenarios are those that you pay less to reduce the amount of CO<sub>2</sub> emission. Table 6.2 portrays that emission tax and restriction scenarios, and some combined scenarios that include tax and high CCS (CCSHT2, C\_40TAX2, C\_40CCSH, C4CCSHT2, and NUCFTAX2) have the highest electricity CO<sub>2</sub> emission savings per unit electricity sector cost increase. The RS\_FP40 and RS\_CCSH scenarios are the most undesirable scenarios regarding electricity CO<sub>2</sub> emission savings per total electricity cost savings because; not only the total electricity costs of these scenarios are higher than that of the base scenario, but also the amount of CO<sub>2</sub> emitted is higher than that of the base scenarios.

Table 6.3. Electricity sector costs and CO<sub>2</sub> emissions by scenarios.

	SCENARIOS	TOTAL ELECTRICITY SECTOR COSTS (M Pounds)	TOTAL ELECTRICITY SECTOR COST INCREASES (M Pounds)	ELECTRICITY SECTOR CO <sub>2</sub> EMISSIONS (kt)	ELECTRICITY SECTOR CO <sub>2</sub> EMISSION SAVINGS (kt)	ELECTRICITY SECTOR CO <sub>2</sub> EMISSION SAVINGS / TOTAL ELECTRICITY SECTORS COST INCREASES (kt/M Pounds)
1	BASE	174,003		14,308,605		
2	C_40CCSH	238,473	64,470	3,130,283	11,178,322	173
3	C_40FP80	307,524	133,521	1,519,306	12,789,299	96
4	C_40NUCF	261,070	87,067	2,708,370	11,600,235	133
5	C_40TAX2	236,565	62,562	3,135,398	11,173,207	179
6	C4CCSHT2	238,473	64,470	3,130,283	11,178,322	173
7	C4CHF8T2	307,269	133,266	1,519,412	12,789,193	96
8	C4CHFP80	307,269	133,266	1,519,412	12,789,193	96
9	C4FP80T2	307,524	133,521	1,519,306	12,789,299	96

Table 6.4. Electricity sector costs and CO<sub>2</sub> emissions by scenarios (cont.).

10	C4NFF8T2	315,813	141,810	1,425,868	12,882,737	91
11	C4NFFP80	315,813	141,810	1,425,868	12,882,737	91
12	C4NFT2	261,070	87,067	2,708,370	11,600,235	133
13	CCSHFP80	224,544	50,541	12,963,616	1,344,989	27
14	CCSHT2	178,182	4,179	11,432,806	2,875,799	688
15	CHFP80T2	234,872	60,869	9,093,565	5,215,040	86
16	FP80TAX2	230,410	56,407	10,844,927	3,463,678	61
17	NFP80T2	259,378	85,375	7,801,833	6,506,772	76
18	NUCFFP80	258,830	84,827	9,204,380	5,104,225	60
19	NUCF TAX2	201,790	27,787	10,234,292	4,074,313	147
20	RS_C_20	193,247	19,244	8,586,609	5,721,996	297
21	RS_C_40	238,607	64,604	3,135,398	11,173,207	173
22	RS_CCSH	174,785	782	14,668,273	-359,668	-460
23	RS_CCSL	172,217	-1,786	14,505,596	-196,991	110
24	RS_FP40	193,892	19,889	14,742,594	-433,989	-22
25	RS_FP80	223,889	49,886	12,160,327	2,148,278	43
26	RS_NUCF	200,683	26,680	10,817,858	3,490,747	131
27	RS_NUCS	182,764	8,761	13,614,538	694,067	79
28	RS_TAX10	174,189	186	13,701,637	606,968	3263
29	RS_TAX20	175,117	1,114	13,513,444	795,161	714
30	RS_TAX40	186,047	12,044	9,310,365	4,998,240	415

Table 6.5. Electricity sector cost increases by scenarios (sorted).

SCENARIOS	TOTAL ELECTRICITY SECTOR COSTS (M Pounds)	TOTAL ELECTRICITY SECTOR COST INCREASES (M Pounds)	TOTAL ELECTRICITY SECTOR COSTS INCREASING RATE
C4NFF8T2	315,813	141,810	81%
C4NFFP80	315,813	141,810	81%
C_40FP80	307,524	133,521	77%
C4FP80T2	307,524	133,521	77%

Table 6.6. Electricity sector cost increases by scenarios (sorted) (cont.).

C4CHF8T2	307,269	133,266	77%
C4CHFP80	307,269	133,266	77%
C_40NUCF	261,070	87,067	50%
C4NFT2	261,070	87,067	50%
NFP80T2	259,378	85,375	49%
NUCFFP80	258,830	84,827	49%
RS_C_40	238,607	64,604	37%
C_40CCSH	238,473	64,470	37%
C4CCSHT2	238,473	64,470	37%
C_40TAX2	236,565	62,562	36%
CHFP80T2	234,872	60,869	35%
FP80TAX2	230,410	56,407	32%
CCSHFP80	224,544	50,541	29%
RS_FP80	223,889	49,886	29%
NUCFTAX2	201,790	27,787	16%
RS_NUCF	200,683	26,680	15%
RS_FP40	193,892	19,889	11%
RS_C_20	193,247	19,244	11%
RS_TAX40	186,047	12,044	7%
RS_NUCS	182,764	8,761	5%
CCSHT2	178,182	4,179	2%
RS_TAX20	175,117	1,114	1%
RS_CCSH	174,785	782	0%
RS_TAX10	174,189	186	0%
<b>BASE</b>	<b>174,003</b>	<b>0</b>	<b>0%</b>
RS_CCSL	172,217	-1,786	-1%

Table 6.7. Electricity sector CO<sub>2</sub> emissions and reduction rate (sorted).

<b>SCENARIOS</b>	<b>ELECTRICITY SECTOR CO<sub>2</sub> EMISSIONS</b>	<b>ELECTRICITY SECTOR CO<sub>2</sub> EMISSION SAVINGS</b>	<b>ELECTRICITY SECTOR CO<sub>2</sub> EMISSION REDUCTION RATE</b>
C4NFF8T2	1,425,868	12,882,737	90%
C4NFFP80	1,425,868	12,882,737	90%
C_40FP80	1,519,306	12,789,299	89%
C4FP80T2	1,519,306	12,789,299	89%
C4CHF8T2	1,519,412	12,789,193	89%
C4CHFP80	1,519,412	12,789,193	89%
C_40NUCF	2,708,370	11,600,235	81%
C4NFT2	2,708,370	11,600,235	81%
C_40CCSH	3,130,283	11,178,322	78%
C4CCSHT2	3,130,283	11,178,322	78%
C_40TAX2	3,135,398	11,173,207	78%
RS_C_40	3,135,398	11,173,207	78%
NFP80T2	7,801,833	6,506,772	45%
RS_C_20	8,586,609	5,721,996	40%
CHFP80T2	9,093,565	5,215,040	36%
NUCFP80	9,204,380	5,104,225	36%
RS_TAX40	9,310,365	4,998,240	35%
NUCFP80	10,234,292	4,074,313	28%
RS_NUCF	10,817,858	3,490,747	24%
FP80TAX2	10,844,927	3,463,678	24%
CCSHT2	11,432,806	2,875,799	20%
RS_FP80	12,160,327	2,148,278	15%
CCSHFP80	12,963,616	1,344,989	9%
RS_TAX20	13,513,444	795,161	6%
RS_NUCS	13,614,538	694,067	5%
RS_TAX10	13,701,637	606,968	4%
RS_CCSL	14,505,596	-196,991	-1%
RS_CCSH	14,668,273	-359,668	-3%
RS_FP40	14,742,594	-433,989	-3%
BASE	14,308,605		

Table 6.4. illustrates the CO<sub>2</sub> emission related results. When the results are analyzed, it can be inferred that the most environmentally friendly scenarios, considering reductions in total amount of CO<sub>2</sub> emissions are C4NFF8T2, C4NFFP80, C\_40FP80, C4FP80T2, C4CHF8T2, C4CHFP80, C\_40NUCF, C4NFT2, C\_40CCSH, C4CCSHT2, C\_40TAX2 and RS\_C\_40, respectively (CO<sub>2</sub> emission reduction rate is higher than 78% for each of them, as can be seen in Table 6.4). It should be noted that all of these scenarios feature 40% emission reduction constraints. The fast nuclear scenario and its variants are also so successful in decreasing CO<sub>2</sub> emissions. For each of them have at least 24% CO<sub>2</sub> emission reduction rate.

Additionally, when electricity sector CO<sub>2</sub> emissions savings per unit electricity cost increase are considered, the best scenarios are the RS\_TAX10 scenario, CCSHT2 and C\_40CCSH scenarios.

Table 6.5 displays the total CO<sub>2</sub> emissions of the electricity sector, the total CO<sub>2</sub> emissions and the respective share of CO<sub>2</sub> emissions of the electricity sector in total emissions associated with each scenario. As can be seen from the Table 6.5, the scenarios which feature largest such shares are the RS\_CCSH and the RS\_FP40 scenarios, and those which feature lowest such shares are the C4NFFP80 and the C4NFF8T2 scenarios. In other words, policies such as the C4NFFP80 and the C4NFF8T2 scenarios lead to “comparatively clean” energy sector, while policies such as RS\_CCSH and the RS\_FP40 lead to a comparatively polluting energy sector. It should also be underlined that, policies such as the C4NFFP80 and the C4NFF8T2 not only lead to a clean energy sector but also lead to the lowest overall emissions.

Table 6.8. Electricity sector CO<sub>2</sub> emissions, total CO<sub>2</sub> emissions of all sectors by scenarios.

	SCENARIOS	ELECTRICITY SECTOR CO <sub>2</sub> EMISSIONS (kt)	TOTAL CO <sub>2</sub> EMISSIONS OF ALL SECTORS (kt)	PERCENTAGE OF THE ELECTRICITY SECTOR EMISSIONS
1	BASE	14,308,605	50,469,840	28.4%
2	C_40CCSH	3,130,283	31,335,612	10.0%
3	C_40FP80	1,519,306	31,354,630	4.8%
4	C_40NUCF	2,708,370	31,337,624	8.6%
5	C_40TAX2	3,135,398	31,335,612	10.0%
6	C4CCSHT2	3,130,283	31,335,612	10.0%
7	C4CHF8T2	1,519,412	31,354,633	4.8%
8	C4CHFP80	1,519,412	31,354,633	4.8%
9	C4FP80T2	1,519,306	31,354,630	4.8%
10	C4NFF8T2	1,425,868	31,354,446	4.5%
11	C4NFFP80	1,425,868	31,354,446	4.5%
12	C4NFT2	2,708,370	31,337,624	8.6%
13	CCSHFP80	12,963,616	48,115,434	26.9%
14	CCSHT2	11,432,806	46,367,499	24.7%
15	CHFP80T2	9,093,565	42,762,048	21.3%
16	FP80TAX2	10,844,927	44,513,855	24.4%
17	NFP80T2	7,801,833	41,487,764	18.8%
18	NUCFP80	9,204,380	44,361,583	20.7%
19	NUCF TAX2	10,234,292	45,311,400	22.6%
20	RS_C_20	8,586,609	40,934,970	21.0%
21	RS_C_40	3,135,398	31,335,612	10.0%
22	RS_CCSH	14,668,273	50,822,442	28.9%
23	RS_CCSL	14,505,596	50,668,251	28.6%
24	RS_FP40	14,742,594	51,042,139	28.9%
25	RS_FP80	12,160,327	47,305,321	25.7%
26	RS_NUCF	10,817,858	46,983,861	23.0%
27	RS_NUCS	13,614,538	49,771,592	27.4%
28	RS_TAX10	13,701,637	49,393,336	27.7%
29	RS_TAX20	13,513,444	48,429,594	27.9%
30	RS_TAX40	9,310,365	42,927,861	21.7%

Table 6.9. The tax amounts for each period by applied tax scenarios.

Scenarios	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051	Total Tax	Electricity Sector Cost	Total System Cost
BASE	0	0	0	0	0	0	0	0	0	0	0	174,003	3,588,205
C_40TAX2	0	0	1,401	1,399	1,424	1,395	1,381	1,379	1,400	1,408	55,935	236,565	3,686,708
C4CCSHT2	0	0	1,401	1,399	1,424	1,395	1,381	1,379	1,400	1,408	55,935	238,473	3,686,477
C4CHF8T2	0	0	1,401	1,399	1,424	1,395	1,381	1,379	1,400	1,408	55,935	307,269	3,839,154
C4FP80T2	0	0	1,401	1,399	1,424	1,395	1,381	1,379	1,400	1,408	55,935	307,524	3,839,410
C4NFF8T2	0	0	1,401	1,399	1,424	1,395	1,381	1,379	1,400	1,408	55,935	315,813	3,841,520
C4NFT2	0	0	1,401	1,399	1,424	1,395	1,381	1,379	1,400	1,408	55,935	261,070	3,697,779
CCSHT2	0	0	2,179	2,168	2,191	2,168	2,137	2,099	2,090	2,113	85,732	178,182	3,596,471
CHFP80T2	0	0	2,217	2,103	2,100	1,969	1,939	1,910	1,871	1,910	80,089	234,872	3,769,201
FP80TAX2	0	0	2,222	2,096	2,103	1,995	2,004	2,000	1,998	2,055	82,356	230,410	3,763,432
NFP80T2	0	0	2,181	2,057	2,032	1,806	1,847	1,860	1,832	1,866	77,404	259,378	3,777,230
NUCFTAX2	0	0	2,151	2,118	2,135	2,102	2,059	2,046	2,050	2,066	83,642	201,790	3,613,908
RS_TAX10	0	0	1,148	1,154	1,174	1,154	1,141	1,147	1,144	1,155	46,084	174,189	3,588,731
RS_TAX20	0	0	2,181	2,172	2,217	2,215	2,205	2,209	2,236	2,273	88,543	175,117	3,590,646
RS_TAX40	0	0	4,191	4,147	3,781	3,602	3,695	3,756	3,961	4,146	156,391	186,047	3,608,640

When Tables 6.4 and 6.6 are analyzed, it can be seen that total electricity sector costs of “C4NFF8T2 and C4NFFP80”, “C\_40FP80 and C4FP80T2”, “C4CHF8T2 and C4CHFP80”, “C\_40NUCF and C4NFT2”, “C\_40CCSH and C4CCSHT2” scenarios are the same as it is explained in the previous sections because taxes are negative costs that are paid to government by consumers or producers.

In a nutshell, this thesis study provides prominent information about Turkey’s electricity sector. Furthermore, it gives significant comments and explanatory comments to decision makers, policy makers and researchers about future of Turkey’s energy policy. The energy sector of Turkey is developing rapidly, so the regarding data must be updated as time passes. Different scenarios with various underlying assumptions can be accomplished for future analyses.

## APPENDIX A: TECHNOLOGICAL DETAILS IN THE BASE SCENARIO

Table A.1. Availability, fix and variable O&M costs and installed power of electricity technologies in the BASE scenario.

Technology	Availability (Fraction)		Fix O&M Cost (M pound/GW)		Variable O&M Cost (M pound/PJ)		Investment Cost (M pound/GW)		Installed Power (GW)	
	2011	2021	2011	2021	2011	2021	2011	2021	2011	2021
E_BIOGAS_C	0.9	0.9	49.4023	49.4023	0	0	1111	1111	0.0249	0.0083
E_BIOGAS_D	0.95	0.95	90	90	6.2	6.2	3200	3200	0.0047	0
E_BIOMAS_E	0.85	0.85	42	42	0.13	0.13	1575	1575	0.063	0.0315
E_BIOMAS20	0.85	0.85	42	42	0.13	0.13	1409	1409	0	0
E_BIOMAS30	0.85	0.85	42	42	0.13	0.13	1304	1304	0	0
E_BIOMAS40	0.85	0.85	42	42	0.13	0.13	1198	1198	0	0
E_BIOMASGT	0.9	0.9	7	7	0.556	0.556	800	800	0	0
E_COA_E	0.5572	0.5572	15.2912	15.2912	0.326	0.326	750	750	6.852	4.568
E_COA_M	0.7227	0.7227	22.8259	22.8259	0.3204	0.3204	758	758	2.8543	1.9029
E_COA_SGB	0.8374	0.8374	23.0476	23.0476	0.2238	0.2238	765	765	0.3	0.2
E_COA_SGL	0.6113	0.6113	25.6585	25.6585	0.2597	0.2597	765	765	1.772	1.1813
E_COA_SPB	0.8374	0.8374	23.0476	23.0476	0.2238	0.2238	765	765	0.1298	0.0865
E_COA_SPL	0.6113	0.6113	25.6585	25.6585	0.2597	0.2597	765	765	0.753	0.502
E_COACO_20	0.9	0.9	18.7	18.7	0.3055	0.3055	767.8	767.8	0	0
E_COACO_C1	0.9	0.9	28.6	28.6	0.75	0.75	1064.8	1064.8	0	0
E_COACO_C2	0.9	0.9	28.6	28.6	0.75	0.75	916.3	916.3	0	0
E_COAIG_20	0.9	0.9	19	19	0.3333	0.3333	862	862	0	0
E_COAIG_30	0.9	0.9	19	19	0.3333	0.3333	835	835	0	0
E_COAIG_C2	0.9	0.9	26	26	0.7222	0.7222	1100	1100	0	0
E_COAIG_C3	0.9	0.9	26	26	0.7222	0.7222	944	944	0	0
E_COAPF_20	0.9	0.9	17	17	0.3055	0.3055	698	698	0	0
E_COAPF_30	0.9	0.9	17	17	0.3055	0.3055	635	635	0	0
E_COAPF_C2	0.9	0.9	26	26	0.75	0.75	833	833	0	0
E_COAPF_C3	0.9	0.9	26	26	0.75	0.75	802	802	0	0
E_DIE_E	0.8	0.8	0.434	0.434	1.24	1.24	500	500	0.21	0.21
E_DIE_EP	0.9	0.9	0.434	0.434	1.24	1.24	500	500	0.055	0.05
E_GEO	0.7	0.7	20	20	0	0	750	750	0.114	0.0855
E_HFO_E	0.8	0.8	15.9	15.9	0.0735	0.0735	500	500	0.8	0.8
E_HFO_EP	0.8	0.8	15.9	15.9	0.0735	0.0735	500	500	0.8125	0.8125
E_HFO_NGA	0.412	0.412	3	3	0.0146	0.0146	500	500	3.3	3
E_HYD_LG	0.4	0.4	80	80	1.9394	1.9394	800	800	6.3613	4.5438

Table A.1. Availability, fix and variable O&M costs and installed power of electricity technologies in the BASE scenario (cont.).

<b>E_HYD_LP</b>	0.4	0.4	80	80	1.9394	1.9394	800	800	2.3542	1.6816
<b>E_HYD_MEG</b>	0.4	0.4	82.5	82.5	2	2	825	825	3.5539	2.5385
<b>E_HYD_MEP</b>	0.4	0.4	82.5	82.5	2	2	825	825	1.5445	1.1032
<b>E_HYD_MG</b>	0.372	0.372	145	145	3.5151	3.5151	1450	1450	0.0324	0.0232
<b>E_HYD_MP</b>	0.372	0.372	145	145	3.5151	3.5151	1450	1450	0.0171	0.0122
<b>E_HYD_SG</b>	0.4	0.4	85	85	2.0606	2.0606	850	850	0.6832	0.488
<b>E_HYD_SP</b>	0.4	0.4	85	85	2.0606	2.0606	850	850	0.6147	0.4391
<b>E_LGAS</b>	0.7	0.7	15	15	0	0	980	980	0.0041	0.0014
<b>E_NGA_E</b>	0.568	0.568	0.43	0.43	1.543	1.543	389	389	0	0
<b>E_NGA_LGTC</b>	0.8306	0.8306	2.0097	2.0097	0.5653	0.5653	395.7784	395.7784	2.503	2.503
<b>E_NGA_LPCC</b>	0.7383	0.7383	5.319	5.319	0.5653	0.5653	415.5673	415.5673	1.9887	1.9887
<b>E_NGA_LPCR</b>	0.6891	0.6891			0.5653	0.5653	155.8377	155.8377	0	0
<b>E_NGA_LPGR</b>	0.8624	0.8624			0.0142	0.0142	123.6684	123.6684	0	0
<b>E_NGA_LPGT</b>	0.924	0.924	2.1973	2.1973	0.0142	0.0142	329.7823	329.7823	0.6136	0.6136
<b>E_NGA_LTCR</b>	0.7752	0.7752			0.5653	0.5653	148.4169	148.4169	0	0
<b>E_NGA_MGTC</b>	0.9	0.9	3	3	0.5556	0.5556	400	400	1.4893	1.4893
<b>E_NGA_S_GT</b>	0.912	0.912	3.687	3.687	0.0113	0.0113	336.378	336.378	0.143	0.143
<b>E_NGACCP</b>	0.8	0.8	7.94	7.94	0.5556	0.5556	420	420	0	0
<b>E_NGAGT_20</b>	0.9	0.9	6.6557	6.6557	0.556	0.556	380	380	0	0
<b>E_NGAGT_30</b>	0.9	0.9	6.2462	6.2462	0.556	0.556	357	357	0	0
<b>E_NGAGT_C2</b>	0.9	0.9	12.075	12.075	0.51	0.51	598	598	0	0
<b>E_NGAGT_C3</b>	0.9	0.9	12.075	12.075	0.5572	0.5572	502	502	0	0
<b>E_NGAGT_C4</b>	0.9	0.9							0	0
<b>E_NGALPGTC</b>	0.8306	0.8306	2.0097	2.0097	0.5653	0.5653	395.7784	395.7784	4.7123	4.7123
<b>E_NUCAGR_E</b>	0.9	0.9	42.8	42.8	0.045	0.045	3826	3826	0	0
<b>E_NUCEP_15</b>	0.85	0.85	35	35	0.066	0.066	2965.4	2965.4	0	0
<b>E_NUCEP_20</b>	0.9	0.9	35	35	0.066	0.066	2100	2100	0	0
<b>E_NUCGT_30</b>	0.9	0.9	14.7	14.7	0.099	0.099	3573	3573	0	0
<b>E_NUCMAG_E</b>	0.9	0.9	42.8	42.8	0.045	0.045	5556	5556	0	0
<b>E_NUCPWR_E</b>	0.9	0.9	42.8	42.8	0.045	0.045	3826	3826	0	0
<b>E_WND1_O</b>	0.47	0.47	27	27	0	0	765.1072	691.9493	0.1958	0.1175
<b>E_WND2_O</b>	0.43	0.43	27	27	0	0	765.1072	691.9493	1.1622	0.6973
<b>E_WND3_O</b>	0.39	0.39	27	27	0	0	765.1072	691.9493	0	0
<b>E_WND5_O</b>	0.34	0.34	27	27	0	0	765.1072	691.9493	0	0
<b>E_WND6_O</b>	0.29	0.29	27	27	0	0	765.1072	691.9493	0	0
<b>ECOAIGCH2</b>	0.9	0.9	26	26	0.7222	0.7222	1100	1100	0	0
<b>ECOAIGCH3</b>	0.9	0.9	26	26	0.7222	0.7222	994	994	0	0
<b>ECOAIGCH4</b>	0.9	0.9	26	26	0.7222	0.7222	944	944	0	0
<b>EWAV--10</b>	0.39	0.39	203	195	0	0	1947.47	1766.516	0	0
<b>E_COACHP_N</b>	0.4412	0.4412	13.125	13.125	0.7248	0.7248	781.25	781.25	0	0
<b>E_COKCHP</b>	0.5469	0.5469	0.43	0.43	1.543	1.543	1000	1000	0	0
<b>E_COKCHP_N</b>	0.5469	0.5469	0.43	0.43	1.543	1.543	1000	1000	0	0

Table A.1. Availability, fix and variable O&M costs and installed power of electricity technologies in the BASE scenario (cont.).

<b>E_HFOCHP_E</b>	0.6239	0.6239	13.125	13.125	0.724	0.724	781.25	781.25	0	0
<b>E_HFOCHP_N</b>	0.6239	0.6239	13.125	13.125	0.724	0.724	781.25	781.25	0.4742	0.1581
<b>E_NGA_MGTS</b>	0.6871	0.6871	7.94	7.94	0.724	0.724	781.25	781.25	0.2557	0.0853
<b>E_NGAGT_D</b>	0.6871	0.6871	7.94	7.94	0.724	0.724	550	550	0	0
<b>E_NGAGT_I</b>	0.6871	0.6871	7.94	7.94	0.724	0.724	550	550	0	0





## APPENDIX C: THE LIST OF SCENARIOS

Table C.1. The list of generated scenarios.

BASE	The Base Scenario
BAUSOLF	Previous Study's Base Scenario
RS_C_20	The 20% Emission Restriction Scenario
RS_C_40	The 40% Emission Restriction Scenario
RS_NUCF	The Fast Nuclear Scenario
RS_NUCS	The Slow Nuclear Scenario
RS_CCSH	The High CCS Scenario
RS_CCSL	The Low CCS Scenario
RS_TAX10	10 TL tax per tonne of CO <sub>2</sub> Emission Scenario
RS_TAX20	20 TL tax per tonne of CO <sub>2</sub> Emission Scenario
RS_TAX40	40 TL tax per tonne of CO <sub>2</sub> Emission Scenario
RS_FP40	40% Fuel Price Increase Scenario
RS_FP80	80% Fuel Price Increase Scenario
C_40TAX2	The Emission Restriction and Tax Scenario
C_40FP80	The Emission Restriction and Fuel Price Increase Scenario
FP80TAX2	The Fuel Price Increase and Emission Tax Scenario
C4FP80T2	The Emission Restriction, Fuel Price Increase and Tax Scenario
NUCF TAX2	The Nuclear and Emission Tax Scenario
NUCF FP80	The Nuclear and Fuel Price Increase Scenario
NFP80T2	The Fast Nuclear, Fuel Price Increase and Emission Tax Scenario
C_40NUCF	The Emission Restriction and Nuclear Scenario
C4NFT2	The Nuclear, Emission Restriction and Tax Scenario
C4NFP80	The Nuclear, Emission Restriction and Fuel Price Increase Scenario
C4NFP8T2	The Nuclear, Emission Restriction, Fuel Price Increase and Emission Tax Scenario
CCSHT2	The CCS and Tax Scenario
CCSHFP80	The CCS and Fuel Price Increase Scenario
CHFP80T2	The CCS, Fuel Price Increase and Tax Scenario
C_40CCSH	The CCS and Emission Restriction Scenario
C4CCSHT2	The CCS, Emission Restriction and Tax Scenario
C4CHFP80	The CCS, Emission Restriction and Fuel Price Increase Scenario
C4CHF8T2	The CCS, Fuel Price Increase, Emission Restriction and Tax Scenario

## REFERENCES

1. European Commission, “The EU Climate and Energy Package”, 2012, [http://ec.europa.eu/clima/policies/package/index\\_en.htm](http://ec.europa.eu/clima/policies/package/index_en.htm), accessed at September 2012.
2. Republic of Turkey Ministry of Foreign Affairs, “United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol”, [http://www.mfa.gov.tr/united-nations-framework-convention-on-climate-change-\\_unfccc\\_-and-the-kyoto-protocol.en.mfa](http://www.mfa.gov.tr/united-nations-framework-convention-on-climate-change-_unfccc_-and-the-kyoto-protocol.en.mfa), accessed at December 2012.
3. Karali, N., *Design And Development of a Large Scale Energy Model*, Ph.D. Thesis, Boğaziçi University, 2011.
4. Cirit, F., *Evaluation Of Energy Supply-Demand Balance and CO<sub>2</sub> Emissions from The Transport Sector in Turkey Based on Technologically Detailed Markal Based Energy Modeling*, M.S. Thesis, Boğaziçi University, 2011.
5. Alemdar, F., *Technologically Detailed Modeling and Analysis of Industrial Energy Use and CO<sub>2</sub> Emissions in Turkey within The Framework of a MARKAL Based Bottom-up National Energy Model*, M.S. Thesis, Boğaziçi University, 2010.
6. Intergovernmental Panel on Climate Change, “Top-down and Bottom-up Models”, <http://www.ipcc.ch/ipccreports/tar/wg3/index.php?idp=310>, accessed at December 2012.
7. Böhringer, C., and T. F. Rutherford, “Combining Top-Down and Bottom-up in Energy Policy Analysis: A Decomposition Approach”, *Centre for European Economic Research, Discussion Paper*, No. 06-007, 2006.
8. International Energy Agency Energy Technology Systems Analysis Program, “MARKAL”, <http://www.iea-etsap.org/web/Markal.asp>, accessed at December 2012.

9. Loulou, R., G. Goldstein, K. Noble, *Documentation for the MARKAL Family of Models*, Energy Technology Systems Analysis Programme, 2004.
10. *Answer v6 – MARKAL User Manual*, Noble-Soft Systems Pty Ltd., New South Wales, 2004.
11. Seebregts, A. J., G. A. Golstein, and K. Smekens, “Energy/environmental modeling with the MARKAL family of models”, *Proceedings of International Conference on Operations Research*, 2001.
12. Hughes, A., M. Haw, H. Winkler, A. Marquard, and B. Merven, *Energy Emissions: A Modelling Input into the Long Term Mitigation Scenarios Process, LTMS Input Report 1*, Energy Research Centre, Cape Town, 2007.
13. Goldstein, G.A., L. A. Goudarzi, P. Delaquil, and E. Wright, *NE-9 MARKAL Structure, Data and Calibration*, NCASP by International Resources Group, 2007.
14. International Energy Agency, “Energy Technology Systems Analysis Program (ETSAP)”, <http://www.iea-etsap.org/web/index.asp>, accessed at December 2012.
15. Suganthi, L., and A. A. Samuel, “Energy Models for Demand Forecasting—A review”, *Renewable and Sustainable Energy Reviews*, Vol. 16, pp. 1223-1240, 2012.
16. Smekens, K. E. L., and R. Morales, “Response from a MARKAL Technology Model to the EMF Scenario Assumptions”, *Energy Economics*, Vol. 26, pp. 655-674, 2004.
17. Kumbaroğlu, G., R. Madlener, and M. Demirel, “A real options evaluation model for the diffusion prospects of new renewable power generation technologies”, *Energy Economics*, Vol.30, pp.1882-1908, 2008.
18. Schulz, T. F., L. Barreto, S. Kypreos, and S. Stucki, “Assessing Wood-based Synthetic Natural Gas Technologies Using the SWISS-MARKAL Model”, *Energy*, Vol. 32, pp. 1948-1959, 2007.

19. Aboumahboub, T., K. Schaber, U. Wagner, and T. Hamacher, "On the CO<sub>2</sub> Emissions of the Global Electricity Supply Sector and the Influence of Renewable Power-modelling and Optimization", *Energy Policy*, Vol. 42, pp. 297-314, 2012.
20. Mondal, A. H., J. Mathur, and M. Denich, "Impacts of CO<sub>2</sub> emission constraints on technology selection and energy resources for power generation in Bangladesh", *Energy Policy*, Vol. 39, pp. 2043-2050, 2011.
21. Broek, M. V. D., A. Faaij, and W. Turkenberg, "Planning for an Electricity Sector with Carbon Capture and Storage: Case of the Netherlands", *International Journal of Greenhouse Gas Control*, Vol. 2, pp.105-129, 2008.
22. Tunc, M., U. Camdali, and C. Parmaksizoglu, "Comparison of Turkey's Electrical Energy Consumption and Production with Some European Countries and Optimization of Future Electrical Power Supply Investments in Turkey", *Energy Policy*, Vol. 34, pp. 50-59, 2006.
23. Kydes, A., "Primary Energy", 2007, [http://www.eoearth.org/article/Primary\\_energy](http://www.eoearth.org/article/Primary_energy), accessed at December 2012.
24. Bhattacharyya, S. C., *Energy Economics: Concepts, Issues, Markets and Governance*, Springer-Verlag, London, 2011.
25. *BP Statistical Review of World Energy June 2012*, BP, London, 2012.
26. International Energy Agency, *International Energy Outlook 2011 edition*, Organization for Economic Cooperation & Development, 2011.
27. International Energy Agency, *2011 Key World Energy Statistics*, Organization for Economic Cooperation and Development, Paris, 2011.
28. Republic of Turkey Ministry of Environment and Urbanization, *National Climate Change Action Plan*, Ankara, 2011.

29. Republic of Turkey Ministry of Energy and Natural Resources, *Enerji ve Tabii Kaynaklar Bakanlığı ile Bağlı ve İlgili Kuruluşlarının Amaç ve Faaliyetleri*, Ankara, 2011.
30. International Energy Agency, “Total Primary Energy Supply of Turkey”, 2011, [https://www.iea.org/stats/pdf\\_graphs/TRTPES.pdf](https://www.iea.org/stats/pdf_graphs/TRTPES.pdf), accessed at December 2012.
31. *World electricity generation by source of energy: Terawatt hours (TWh), dans OECD Factbook 2013*, Éditions OCDE, doi : 10.1787/factbook-2013-graph114-en, accessed at January 2013.
32. Türkyılmaz, O., and C. Özgiresun, *Türkiye'nin Enerji Görünümü 2012*, TMMOB Türkiye Makine Mühendisleri Odası, 2012.
33. *Kömür (Linyit) Sektör Raporu-2009*, General Directorate of Turkish Coal Enterprises, Ankara, 2010.
34. Turkish Statistical Institute, “Seragazi Emisyon Envanteri - Dönemi: 1990-2010”, <http://www.tuik.gov.tr/PreHaberBultenleri.do?id=10829>, accessed at December 2012.
35. United Nations Climate Change Secretariat, “Summary of GHG Emissions for Turkey”, [http://unfccc.int/files/ghg\\_emissions\\_data/application/pdf/tur\\_ghg\\_profile.pdf](http://unfccc.int/files/ghg_emissions_data/application/pdf/tur_ghg_profile.pdf), accessed at December 2012.
36. European Environment Agency, “Emissions From Public Electricity and Heat Production - Explanatory Indicators”, <http://www.eea.europa.eu/data-and-maps/indicators/emissions-co2-so2-nox-from-1/assessment-1>, accessed at August 2011.
37. *Elektrik Üretim Sektör Raporu*, Elektrik Üretim A.Ş., 2010.
38. *Enerji Raporu 2010*, World Energy Council Turkish National Committee, Ankara, 2010.

39. Balat, H., “A renewable perspective for sustainable energy development in Turkey: The case of small hydropower plants”, *Renewable and Sustainable Energy Reviews*, Vol. 11, pp. 2152–2165, 2007.
40. Government of Alberta, “Hydroelectric Power”, 2002, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/eng4431](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/eng4431), accessed at December 2012.
41. Kannan, R., and H. Turton, *Documentation on the Development of the Swiss TIMES Electricity Model (STEM-E)*, Paul Scherrer Institut, Switzerland, 2011.
42. Malkoç, Y., “Türkiye Rüzgar Enerjisi Potansiyeli ve Enerji Profilimizdeki Yeri”, [http://130.226.17.201/extra/web\\_docs/turkey/TurkishWindData.pdf](http://130.226.17.201/extra/web_docs/turkey/TurkishWindData.pdf), accessed at September 2012.
43. *Trends in Global Energy Efficiency 2011: Turkey Energy Efficiency Report*, ABB, 2011.
44. Türkyılmaz, O., *Türkiye'nin Enerji Görünümü*, Konya Chamber of Mechanical Engineers, Konya, 2011.
45. Republic of Turkey Ministry of Energy and Resources, “2007 Yılı Genel Enerji Dengesi (Orijinal Birimler)”, [http://www.enerji.gov.tr/EKLENTI\\_VIEW/index.php/raporlar/detayGoster/4903](http://www.enerji.gov.tr/EKLENTI_VIEW/index.php/raporlar/detayGoster/4903), accessed at August 2012.
46. *Elektrik Üretim Sektör Raporu*, Elektrik Üretim A.Ş., 2011.
47. Krohn, S., P.-E. Morthorst, and S. Awerbuch, *The Economics of Wind Energy: A report by the European Wind Energy Association*, The European Wind Energy Association, 2009.
48. National Wind, “Wind Turbine Facts”, <http://www.nationalwind.com/files/NationalWindTurbineFacts.pdf>, accessed at December 2012.

49. Kose, R., “Geothermal energy potential for power generation in Turkey: A case study in Simav, Kutahya”, *Renewable and Sustainable Energy Reviews*, Vol. 11, pp. 497–511, 2007.
50. DB Climate Change Advisors, *Repowering America: Creating Jobs*, Deutsche Bank Group, 2011.
51. Sözen A., E. Arcaklioğlu, M. Özalp, and E. G. Kanit, “Solar-energy potential in Turkey”, *Applied Energy*, Vol. 80, pp. 367–381, 2005.
52. Republic of Turkey Ministry of Energy and Natural Resources PIMS 3367 Turkey First National Communication Project, *Reference Case: Energy Sector Modelling Final Report*, 2006.
53. Republic of Turkey Ministry of Energy and Resources, “2006 Yılı Genel Enerji Dengesi (Orijinal Birimler)”, [http://www.enerji.gov.tr/EKLENTI\\_VIEW/index.php?/raporlar/detaySec/5480](http://www.enerji.gov.tr/EKLENTI_VIEW/index.php?/raporlar/detaySec/5480), accessed at August 2012.
54. Republic of Turkey Ministry of Energy and Resources, “2010 Yılı Enerji Dengesi (Orijinal Birimler)”, [http://www.enerji.gov.tr/EKLENTI\\_VIEW/index.php?/raporlar/detaySec/61543](http://www.enerji.gov.tr/EKLENTI_VIEW/index.php?/raporlar/detaySec/61543), accessed at August 2012.
55. Battisti, R., and A. Corrado, “Evaluation of technical improvements of photovoltaic systems through life cycle assessment methodology”, *Energy*, Vol. 30, pp. 952-967, 2005.
56. Varınca, K. B, and T. M. Gönüllü, “Türkiye’de Güneş Enerjisi Potansiyeli ve Bu Potansiyelin Kullanım Derecesi, Yöntemi ve Yaygınlığı Üzerine Bir Araştırma”, *Proceedings of I. National Solar and Hydrogen Energy Congress*, 2006.
57. Biogas Renewable Energy, “Biogas Composition”, <http://www.biogas-renewable-energy.info/>, accessed at December 2012.

58. U.S. Department of Energy, “Biodiesel”, <http://www.fueleconomy.gov/feg/biodiesel.shtml>, accessed at December 2012.
59. Vogelbusch Biocommodities, “Bioethanol: A Source of Renewable Energy”, <http://www.bioethanol.vogelbusch.com/en/index.php>, accessed at December 2012.
60. Republic Of Turkey Ministry Of Energy And Natural Resources Directorate-General for Renewable Energy, “Biyoeetanol”, <http://www.eie.gov.tr/yenilenebilir/biyoeetanol.aspx>, accessed at December 2012.
61. *Turkish Power Plants*, European Comission, 2009.
62. *İklim Çözümleri: 2050 Türkiye Vizyonu*, World Wild Fund for Nature (WWF)-Turkey, Istanbul, 2009.
63. SOL<sub>2</sub>O Ltd., “Biomass Boilers”, <http://www.sol2o.co.uk/biomass.html>, accessed at December 2012.
64. McNeil Technologies Inc., *Biomass Resource Assessment and Utilization Options for Three Counties in Eastern Oregon*, Oregon Department of Energy, 2003.
65. Murray, R. L., *Nuclear Energy: An Introduction to the Concepts, Systems and Applications of Nuclear Processes*, Butterworth Heinemann, Raleigh, 5<sup>th</sup> Edition, 2000.
66. Friends of The Earth Vlaanderen & Brussel, “Nuclear power and greenhouse gas emissions”, <http://www.motherearth.org/energy/nuclear2.php>, accessed at December 2012.
67. World Nuclear Association, “Nuclear Power in Turkey”, 2012, [http://www.world-nuclear.org/info/inf128-nuclear\\_power\\_in\\_turkey.html](http://www.world-nuclear.org/info/inf128-nuclear_power_in_turkey.html), accessed at December 2012.
68. Turkish Atomic Energy Authority, “Akkuyu - VVER 1200 Nükleer Santrali”, 2012, <http://www.taek.gov.tr/bilgi-kosesi/nukleer-enerji-ve-reaktorler/212-akkuyu-nukleer->

- guc-santrali/1119-akkuyu-vver-1200-nukleer-santrali.html, accessed at December 2012.
69. Republic Of Turkey Ministry Of Energy And Natural Resources, “Hydrogen Energy”, 2010, [http://www.enerji.gov.tr/index.php?dil=en&sf=webpages&b=hidrojenenerjisi\\_EN&bn=225&hn=&nm=40717&id=40739](http://www.enerji.gov.tr/index.php?dil=en&sf=webpages&b=hidrojenenerjisi_EN&bn=225&hn=&nm=40717&id=40739), accessed at December 2012
70. Renewable Energy World, “Hydrogen Energy”, <http://www.renewableenergyworld.com/rea/tech/hydrogen>, accessed at December 2012.
71. Cheng, X., Z. Shi, N. Glass, L. Zhang, J. Zhang, D. Song, Z. S. Liu, H. Wang , and J. Shen , A review of PEM hydrogen fuel cell contamination: Impacts, mechanisms, and mitigation, *Journal of Power Sources*, Vol. 165, pp. 739–756, 2007.
72. *Hydrogen Production Facilities Plant Performance and Cost Comparisons: Final Report*, Parsons Infrastructure and Technology Group, Pennsylvania, 2002.
73. Yılmaz, A. O., and T. Uslu; “The role of coal in energy production - consumption and sustainable development of Turkey”, *Energy Policy*, Vol. 35, pp. 1117–1128, 2007.
74. Elektrik Üretim A.Ş., “Yıllara Göre Kurulu Güç Gelişimi”, <http://www.euas.gov.tr/Sayfalar/YillaraGoreKuruluGucGelisimi.aspx>, accessed at December 2012.
75. Keskinel, F., “Türkiye’de Elektrik Üretimi ve Doğalgaz Kombine Çevrim Santralleri”, *İstanbul Bülten*, Vol. 87, 2006.
76. International Energy Agency, “Topic: Oil”, <http://www.iea.org/topics/oil/>, accessed at October 2012.
77. Acar, Ç., Ç. Metin, F. Gümrah, M. Parlaktuna, and S. Bülbül, *Petrol ve Doğal Gaz*, ODTÜ Geliştirme Vakfı Yayıncılık, Ankara, 2007.

78. Petroleum HPV Testing Group, *Heavy Fuel Oils Category Analysis and Hazard Characterization*, The American Petroleum Institute, 2011.
79. *Technology Data for Energy Plants*, Danish Energy Agency, 2010.
80. Republic of Turkey Energy Market Regulatory Authority, *Natural Gas Market 2011 Sector Report*, Natural Gas Market Department, Ankara, 2012.
81. NaturalGas.org, “Electric Generation Using Natural Gas”, [http://www.naturalgas.org/overview/uses\\_eletrical.asp](http://www.naturalgas.org/overview/uses_eletrical.asp), accessed at December 2012.
82. Ay, S., *Elektrik Enerjisi Ekonomisi*, Birsen Yayınevi, Istanbul, 2008.
83. *Türkiye’de Elektrik Enerjisi Kurulu Gücü*, The Chamber of Electrical Engineers, Ankara, 2012.
84. Turkey Electricity Generation Company (TEAŞ), *Annual Development Of Turkey's Installed Capacity By Primary Energy Resources*, Turkey Electricity Generation Company, 2001.
85. World Energy Council Turkish National Committee, *Türkiye Enerji Raporu 2009*, Ankara, 2009.
86. Elektrik Üretim A.Ş., *EÜAŞ Termik Santral Bilgileri (6,7 ve 10. Maddeler)*, 2011.
87. Elektrik Üretim A.Ş., *Türkiye Elektrik Enerjisi Kuruluş ve Yakıt Cinslerine Göre Kurulu Güç*, 2004.
88. Karayılmazlar, S., N. Saraçoğlu, Y. Çabuk, and R. Kurt, “Biyokütlenin Türkiye’de Enerji Üretiminde Değerlendirilmesi”, *Bartın Orman Fakültesi Dergisi*, Vol. 13, No.19, pp. 63-75, 2011.

89. Yumurtacı, Z., and N. Bekirođlu, “Yenilenebilir Enerji Kaynakları ve Teknolojileri”, *Proceedings of International Symposium on Eco Technologies and Ecological Sites*, 2005.
90. Önal, G., Z. Dođan, and H. Yüce, “Kömür Tüketimi-Termik Santrallar”, *Proceedings of the 8th Coal Congress of Turkey*, 1992.
91. Turkish Electricity Transmission Company Research, Planning and Coordination Department, *Türkiye Elektrik Enerjisi Üretim Planlama Çalışması (2005 – 2020)*, 2004.
92. Karellas, S., I. Boukis, and G. Kontopoulos, “Development of an Investment Decision Tool for Biogas Production from Agricultural Waste”, *Renewable and Sustainable Energy Reviews*, Vol. 14, pp. 1273–1282, 2010.
93. European Commission, *European Price Statistics – An overview*, Office for Official Publications of the European Communities, Luxembourg, 2008.
94. Bureau of Labor Statistics, *Producer Price Indexes – December 2003*, United States Department of Labor, Washington D.C., 2004.
95. Wikipedia, “Tables of Historical Exchange Rates to the United States Dollar”, 2012, [http://en.wikipedia.org/wiki/Tables\\_of\\_historical\\_exchange\\_rates\\_to\\_the\\_United\\_States\\_dollar](http://en.wikipedia.org/wiki/Tables_of_historical_exchange_rates_to_the_United_States_dollar), accessed at September 2012.
96. The Chamber of Electrical Engineers, “Elektrik Enerjisinde Maliyet İncelemesi”, [http://www.emo.org.tr/ekler/df3320b413d8eb7\\_ek.pdf](http://www.emo.org.tr/ekler/df3320b413d8eb7_ek.pdf), accessed at July 2012.
97. Republic of Turkey Energy Market Regulatory Authority, *EPDK 2008 Yılı Faaliyet Raporu*, Ankara, 2009.
98. Keskinel, F., “Türkiye’de Elektrik Üretimi ve Doğalgaz Kombine Çevrim Santralleri”, *Istanbul Chamber of Civil Engineers - Istanbul Bülten*, Vol. 87, pp. 19-26, 2006.