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Greenex Index In Asset Pricing Models: Validating The Carhart Model For Evaluating Energy-Efficient Perspectives

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Abstract
This study discusses validity about "asset pricing models" within respect context based on "S&P Base Greenex Index". With use of the gathered data from 25 companies we apply the "Carhartfour- factor model" and additional risk to evaluate how returns on green investments are explained through multifactor regression, OLS, GRS F test, "Sharpe ratio, and Jensen's alpha". The R^2 about "Carhart four-factor model" with GHG emission of 86-87% is "High" than the R^2 of the "Carhart four-factor model". After reviewing the existing literature, there is a gap identified as the inclusion of climate factors within "asset pricing models" area. This article examines the Green ex index's performance in "asset pricing models" firstly from the perspective of sustainable investing.
Keywords: *Carhart Four Factor Model, greenhouse gas (GHG) emission, Market Risk, Momentum, Size effect, S&P Base Greenex Index, Value Premium.*

INTRODUCTION

Investment and Portfolio analysis utilizes complex models like stock price volatility measurement. It uses Harry Markowitz's portfolio selection and William Sharpe's simplified model. This provides predictive power and understanding of arbitrage pricing theory (S.Chand & V.K.Bhalla). BSE launched by the India's first aspect of carbon efficient that, index, GREENEX, derived through BSE and also IIM Ahmadabad, to promote sustainability and environmental protection among companies (Choudhary & Jain, 2018). "Trade Carbon Ex Ratings Services Private Limited", an Indian company, co-developed the "BSE-GREENEX" Index, a real-time index for diversifying investments under regulatory and statutory requirements (Choudhary & Jain, 2018). Green stock market indices like "BSE-GREENEX" track green business performance and measure carbon emissions (Bhattacharya, 2013). The growing demand for corporate climate change information has led companies to report their emission data to stakeholders through annual and sustainability reports (Charumathi, 2017). Climate change regulations aim to reduce global greenhouse gas emissions through strategies like carbon pricing, driven by public concerns and climate change issues (Borghei-Ghomi & Leung, 2013). India's voluntary commitment to decrease emissions by 33-35% by 2030 (Charumathi, 2017). (Roncalli et al., 2021) Introduces dynamic carbon beta estimation that utilizes Kalman filtering which distinguishes from traditional carbon risk measures where investors favor stocks with negative carbon beta and absolute carbon risk investors favor stocks with close to zero carbon betas.
Impact investigated by incorporating GHG emission into portfolio performances evaluations.

- How valid are the "Carhart four-factor model" and "Carhart model" with green housegas in evaluating investment portfolios?
- What is the remarkable impact about risk in the market, size, and value along with momentum approaches of the risk-return dynamics of sustainable investments?
- Whatistheroledoesgreenhousegasemissionfactorplayintheperformanceof investment portfolios?
- How does the performance about "Carhart four-factor model and Carhart model" with greenhouse gas emission factor in evaluating investment portfolios?

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

S&P Base BSE GREENEX Index or Carbon Index

In2012, the Bombay Stock Exchange introduced "BSEGREENEX" to promote green and sustainable investing in India, an emerging market in its early stages. This was the 25th dynamic index to be included on the BSE (Tripathi & Bhandari, 2012). The index encourages investors to make informed decisions about India's green theme and encourages 25 companies for effectively adopting eco-friendly technologies for reducing carbon footprint. This measures companies through carbon emissions performance (Choudhary & Jain, 2018). To encourage energy practices in Indian corporate, create an inclusive market structure in the initial stage for promoting energy efficiency. GREENEX quantifies environmental performance, by measuring emissions intensity, by dividing total emissions by revenue. This measure is considered to be a close approximation of energy efficiency. (Bhattacharya, 2013).

"Carhart Four Factor Model"

The "Carhart Multifactor Model" extensive aspect "Fama-French Three-Factor Model", incorporating a momentum approach, stocks with huge past returns towards continue for "High" performance in future. The model analyzes the BSEGRNX index as a sustainableinvestmentindicator.(Munawaroh,2015)"Riskpremium,book-to-marketratio, investment and momentum positively" affect expected stock returns. (Carhart, 1997) "The four-factor model" explains stock exchange return variation and shows significant loadings on the momentum factor. Further, the "four-factor model" outperforms "CAPM and three- factor models" in reducing pricing errors. (Claesson & Bask, 2021)

H1: The "Carhart four-factor model" provides an statistically significant explanation of the returns of a portfolio.

H2: The aspect consisting "Carhart four-factor model" exhibit significant relationships with the returns of the portfolio, indicating their relevance in explaining the risk-return of sustainable investment.

b. Greenhouse gas (GHG) emissions of Carbon Intensity

Firms with superior GHG performance are more likely to engage in discretionary disclosure, and listing status plays a significant role in GHG disclosure decisions which suggests that stakeholders' interests also determine disclosure decisions (Borghei-Ghomi & Leung, 2013). Cost of equity and debt financing increase with the level of exposure to climate risk by using carbon dioxide emission rates of publicly traded U.S. electric companies after controlling for firm size, market-to-book ratio, leverage, cash flow volatility, long-term growth rate, asset newness and capital intensity (L. H. Chen & Silva Gao, 2011). Carbon betas are market-based measures that are complementary to carbon intensities or fundamental-based measures when managing investment portfolios, because carbon betas may be viewed as an extension of the current carbon footprint (Roncalli et al., 2021). R&D and private that does not aim to develop cleaner and more energy-efficient technologies does not significantly contribute to reductions in GHG emissions or can even increase GHG emissions (Herzer, 2024). Carbon risk is priced at the stock level and is relevant in a cross-sectional multi-factor analysis. It is more appropriate to define a minimum variance portfolio better than to improve the diversification of a factor investing portfolio (Roncalli et al., 2020). Increased volatility and a large degree of persistence in energy-efficient investing in India can be seen and the COVID-19 pandemic has increased the volatility of the S&P BSE GREENEX Index by 130.155% (Bangur & Bangur, 2023). (Azeem et al., 2022) confirms that Stock Market Capitalization's inverted U relationship with CO2 emissions is evident in both aggregate and regional data. As per (Sandsmark & Vennemo, 2007) A negative correlation was found between climate finance and both longterm and yearly climate risks, indicating that the distribution of climate finance does not align with the actual climate risks faced by South Asian countries.

Further, (Z. Chen & Lu, 2018) propose measuring unobserved usage via CO2 emissions and the model shows stronger pricing power irrespective of "CAPM and CCAPMs". It addresses "joint risk premium and risk- free rate puzzles". Using "the Granger causality test", (Chang et al., 2020) find that significant unidirectional causality is found from stock returns to "CO2 emissions and stock market performance" can influence carbon emissions. (Benedetti et al.,2021). As per (Mukhopadhyay & Sarkar, 2021), Investors receive significant compensation for green indices'risk. (Roncalli et al., 2021) "High"lights the complexity of carbon risk measurement, particularly contrasting "single-factorandtwo- factor models". In the "two-factor model", the sensitivity to market and brown-minus-green factors exhibit more intricate relationships, with the market beta being positive and the brown-minus-green beta potentially being either positive or negative. The incorporation of climaticelementsin “asset pricing models” has been defined as a gap within literature after a careful review.

H3: Greenhouse gas emissions contribute to the risk-adjusted returns of sustainable investments within the S&P Base Greenex Index.

H4: The “Carhart model”with greenhouse gas emissions factor provides significantly different performance evaluation outcomes than the “Carhart four-factor model”.

Data and methodology

“S&P BSE” Base Greenex Index (BSEGRNX) consists of 25 companies that fol”Low” energy- efficient practices that comprise sustainable investment within “S&P BSE” 100 Index. It comprises with the total 25 energy-efficient companies listed in BSE and selected based on their performance in energy efficiency and adherence to sustainable practices. The Greenex index is designed to track the energy efficiency and environmental impact of India’s largest companies.Thesefirmsarefocusingonadoptingrenewableenergytechnologiesandreducing carbon emissions. From February 2012 to March 2023, with 134 no: observations, monthly data for 25 companies within the BSE GREENEX index are used in this research. Data sources include CMIE Prowessdx, climatewatchdata.org, rbi.org.in, investing.com, and the “S&P BSE GREENEX Index” website.Foreachsamplefirm,theresearchtakesintoaccountthefol”Low”ing: month-end adjusted closing share prices, size is determined by market capitalization (multiplying outstanding shares by current share prices) as SMB while value is proxies by “book-equityto market equityratio” “(BE/ME)” as HML. Momentum (monthlyreturnsfrom t-12 to t-2) as WML and GHG emission as HgMLg. Market return (Rm) is obtained using BSE GREENEXindexreturns“(indexmonthlyexcessreturnsareestimatedbysubtractingmonthly returnontheindexbymonthlyrisk-freereturns)”,andrisk-freereturn(Rf)isderivedusing91- day Treasury bills as a proxy.

Mimicking Portfolio

Using an approach similar to that of “Fama & French,1993 methodology”, the present research created “six mimicking portfolios” from the intersections of "size and value," "size and momentum," and "size and greenhouse gas" to determine the corresponding mimicking risk factorsofeach. A single-sort approach is used in June of every (t) year to create two size-based mimicking portfolios based on MC. When it comes to 10:90 breakpoints, the top 10% are "smallstocks,"while90%are"bigstocks."The ranking is updated using the same methodology in June from every year (t+1) till 2023.

Two sets of 2 x 3 portfolios, containing “six portfolios” each, developed by portfolios created via single sort using the double sorting approach. The six size and value “portfolios” that were derived from a single sort are referred to as “SL, SM, SH, BL, BM, and BH”. Big-sizeand”High”-valueequitiesaregroupedintoBH,whereassmallandvaluestocks are grouped into SL. Likewise, the six portfolios for the 2 x 3 size–momentum sorts are identified as SW,SM,SL,BW,BM,andBL. Large-size and winning stocksaregroupedinto BW,whereassmall-sizeandlosingstocksaregroupedintoSL.Sixportfolios,SLg,SM,SHg, BLg, BM, and BHg, were created from a 2 x 3 size -GHG emissions.

Constructionofmimickingportfolios

The econometric models

“Capital Asset Pricing Model(CAPM)”

The total market return (CPM), denoted through RM in the CAPM is frequently a diversified market index with the “S&P 500”

“Rp -Ri=α+Rf+βi(RM−Rf)” (6.1)

Rp-Ri= “Excess return of asset over” “risk-free rate” of return

“Rf= risk-free rate

Bi=Beta ofasset

RM=Expectedreturnofmarketportfolio α=alpha”

The “market risk premium”, (RM), is a crucial component of the model as it implies that investors compensated systematic risk developed through the market by the excess return $(RM-Rf)$.

"Fama-FrenchThree-FactorModel"

Whilethethreecomponentsthatexplainreturnsinthismodel, RM isonce again the market portfolio return.
"Rp -Rf=α+β+(RM−Rf)+sSMB+hHML" (6.2)
β=Beta
α=alpha
"Rp-Rf=Expectedreturnofportfolioorasset" "p Rf=riskfree rate
Rm=Expectedreturnofthemarketportfolio
SM= The excess returns of small-cap stocks over large-cap companies" are representedbythefactorSmallMinusBig.Thesize effectiscapturedbytheSMBfactor. s = Sensitivity of portfolio to size factor, SMB.
"SMB=(SL+SM+SH)/3–(BL+BM+BH)/3
(6.3)
HML=Theexcess returns ofvalue stocks("High"book-to-marketratio) overgrowth

companies("Low"book-to-marketratio)arerepresentedbythefactor"High"Minus"Low".It depicts the influence of value".
h=Sensitivityofportfoliotovaluefactor,HML. Theformulaforthecalculationof HML
"HML=(SH+BH)/2–(SL+BL)/2"
(6.4)
Theassumptionthatsmall-capfirmsandvaluestockshistoricallygenerateextrareturns abovethose explained bythe market aloneis reflectedin the useof the words$SMB$and
HML.

"Carhart Four Factor Model"

It adds a fourth element to reflect the momentum effect in asset returns. Rp-Rf=α+β+Rf+β(RM−Rf)+sSMB+hHML+mWML
(6.5)
β=Beta
α=alpha
"Rp-Rf=excessreturnofassetorportfoliooverrisk-freerateofreturn Rf = risk-free rate
B=Beta
E(Rm)=expectedreturnofmarketportfolio SMB = Small Minus Big, size factor
s=portfolio'ssensitivitytothesizefactor HML = "High" Minus "Low", value factor.
h=portfolio'ssensitivityto thevalue factor"
WML=TheWMLfactor,which representsthereturn differentialbetween winners andlosers,isbasedonresearchshowingthatmomentumstrategies,suchasbuyingwinners and selling losers, have historically been profitable.
m=portfolio'ssensitivitymomentumfactor.
WML=(SW+BW)/2 –(SL+BL)/2 (6.6)

Carhart GHG emission model or Adjusted "Carhart four-factor model" with GHG Emissions Factor

The "Carhart "four-factor model" incorporates greenhousegas emissions, astep towards integrating ESG issues into traditional asset of pricing models. It indicates carbon intensity portfolio firms.
"Rp-Rf=Rf+β(RM−Rf)+sSMB+hHML+mWML+gHgMLg (6.7)
Rp=expectedreturnofportfolio Rf= risk-free rate
B=Beta,thesensitivityofportfoliotomarketriskfactor E(Rm)=expected return of market portfolio
SMB=Sizefactor(small-capstocksversuslarge-capstocks). HML= Value factor (value stocks versus growth stocks).
WML=Momentumfactor(Momentum effectbasedonpast return)"
HgMLg="High"gasMinus"Low"gas,Greenhousegasemissionsfactor,whichexaminesthe influence of companies' carbon emissions on their portfolio returns. The GHG emissions factor measures a company's environmental performance, focusing on its greenhouse gas emissions based on carbon intensity, the amount of emissions relative to revenue.

g=sensitivityofportfoliotogreenhousegasemissionfactor.TheformulaformeasuringHgMLg is as fol"Low"s;
(SHg+BHg)/2−(SLg+BLg)/2 (6.8)

"Results and Discussion"

1.1. "Descriptivestatistics"

Table1 Summary of the statistics of variables using observations 2012:02-2023:03

Statistic	RM-RF	SMB	HML	WML	GHG
Mean	-0.4122	-0.0033	0.5579	1.3177	2.6646
Median	-0.5	0.15	0.2	1.41	2.6685
Minimum	-19.78	-13.95	-10.16	-12.02	2.476
Maximum	13.19	9.68	17.89	14.03	2.87
Std. Dev	4.5568	4.1145	5.1739	5.1032	0.1226
t.statistics	−0.9518	−0.7793	0.07528	−1.119	−1.016

Source: The authors

AsperdatainTable1, market performance analysis, average excess market return underperformed risk-free rate and "small-cap stocks" outperformed large-cap companies, through an SMB mean of almost zero. ""High"book-to-market"companiesoutperformed,withameanof0.5579 and "High" momentum indicates past winners outperformed past losers. Positive GHG emissions measure, 2.6646, indicates an upward trend.

Table2 Descriptivestatistics ofportfolioreturnsusingtheobservations2012:02 -2023:03

	RSMB	RHML	RWML	RHgMLg
Mean	-0.179	-0.425	16.73	-0.23209
Median	-0.225	-0.015	7.815	-0.16
Minimum	-13.03	-19.19	-237.48	-12.47
Maximum	11.7	9.64	455.98	6.56
Std. Dev.	4.3966	5.0341	63.705	2.3984
t. statistics	0.4737	−1.667	−2.508	0.4349

Source: The authors

InTable2,Small-capequitiesunderperformedlarge-capstocks,-0.179,duetorisk."Low"book-to- market ratios outperformed "High" ratios. This implies that those who chose to purchase growth stocks at a "High"er risk received a benefit. The "High" mean of RWML 16.73 indicates successful momentum. Underperformance HML of -0.23209 (0.4349) on growth stocks is not significant enough to be considered reliable.

1.2. "CorrelationMatrix"

Table3 Correlationmatrixofexplanatoryvariables

	"Rm- Rf"	"SMB"	"HML"	WML	GHG
"Rm– Rf"	1				
"SMB"	-0.311	1			
"HML"	0.5455	-0.5826	1		
WML	-0.8122	0.3757	-0.7467	1	
GHG	0.3133	-0.63	0.3774	-0.1556	1

Source: The authors

A "High" negative correlation (-0.8122) between momentum and Rm-Rf indicates that momentum outperforms strongmarkets. Small-cap stocks underperform when value stocks and GHG factors perform well. Negative correlation between HML and GHG and small-cap stocks, making them less attractive to ESG-conscious investors. There is subjected to be positive correlation among momentum as well as SMB(WML,0.3757)suggestingmomentumstrategiesarebeneficialforsmall-capstocks.Finally, moderate to weak correlation between variables, with "Low" beta indicating a weak correlation.

1.3. **Table4** Summary of the statistics of "6portfolioformedonsize_value,size_momentum, size_GHG"

A. " Meanof6portfolios formedonSize_Value,Size_Momentum,and Size_GHG".

2x3 Size_Value

	"Low"	"Medium"	"High"
"Small"	0.0157	0.0161	0.0122
"Big"	0.0188	0.0129	0.0104

2x3 Size_Momentum

	"Low"	"Medium"	"High"
"Small"	0.0191	0.0114	0.0172
"Big"	0.0168	0.0110	0.0193

2x3 Size_GHG

	"Low"	"Medium"	"High"
"Small"	0.0106	0.0105	0.0136
"Big"	0.0110	0.0107	0.0096

Source:The authors

B.Standarddeviationof"6portfoliosformedonSize_Value,Size_Momentum,andSize_GHG".

2x3Size_Value, 2x3

Small	0.0035	0.0051	0.0026
Big	0.0077	0.0047	0.0087

Size_Momentu

	"Low"	"Medium"	"High"
"Small"	0.0053	0.0041	0.0047
"Big"	0.0062	0.0052	0.0049

2x3 Size_GHG

	"Low"	"Medium"	"High"
Small	0.0093	0.0077	0.0063
Big	0.0089	0.0063	0.0043

Source:The authors

A. tstatisticsof "6portfoliosformedonSize_Value,Size_Momentum,andSize_GHG"

2x3 Size_Value

	""Low""	"Medium"	"High"
"Small"	1.83	2.32	2.23
"Big"	2.07	2.43	2.94

2x3 Size_Momentum

	"Low"	"Medium"	"High"
"Small"	1.60	2.72	1.34
"Big"	3.00	2.80	2.98

2x3 Size_GHG

	"Low"	"Medium"	"High"
Small	2.37	3.06	3.48
Big	2.13	2.43	2.34

Source: The authors

The "size,value,momentumandGHGreturns"patternareshowninTable4.In2x3size-value sorted "6portfolios'monthlyaveragereturns"showaclearsizeeffect.Returnsfluctuate,starting "High", dropping, and then rising again assize increases. Inthesize momentumsorted6portfolios'returnanalysis, the small portfolio out performs the big portfolio at a "Low" level with a 1.91% return, indicating a marginal size effect. "Medium"- level returns are close, with a small portfolio slightly better than a big portfolio at 1.14%. At the "Medium" level, both small and big portfolios are quite close in returns, with the small portfolio at 1.14% (t=2.72) performing just slightly better than the big portfolio at 1.10 % (t=.2.80). The difference here is minimal, suggesting that size doesn't have a significant impact at this level. At the "High" level, the big portfolio 1.93% (t=2.98) outperforms the small portfolio 1.72% (t=1.34), reversing the trend seen at the "Low" level. Inmonthlyaveragemeanreturnsofsize-GHGemissionsorted6portfolios,atthe"Low"level ofGHGemission, big portfolios of1.10%(t=2.13)slightlyoutperformsmall portfolios of1.06% (t=2.37).Sizeeffectfluctuateswith"Low"GHG emissionfirms yieldmarginallybetter returnsthan small firms.

Regression Results

Both equal and value weight sregressiontestsofallthemodelsareshowninTables5to10.Tables 5 and 6 depict the equal and value weights of Carhart's "four-factor model" regression with "beta, size,valueandmomentum". The "Carhart four-factor model", withconsistentlypositivealphavalues ranging from 0.055 to 0.053, as alpha is zero. This model works better for big portfolios at "Low" momentum levels and leaves significant returns unexplained for both small and bigportfolios.Thenegativealphavaluesinequalweightsindicateoverestimatedreturnsofsmall and large portfolios with "Medium" and "High" GHG emissions. Further,wetestedsizeportfolioswithbeta,size,value,momentum,andGHGemission, and "The Carhartfour-factor" with GHG emission mode sregressionresultsarepresentedinTables 7and8.Alphavaluesrangefrom−0.085to−0.056andabsolutealpharangesfrom−1.735to −1.92. This model, including the GHG emission factor, portfolio is underperform compared to model predictions and returns are "Low"er than expected. The adjusted R2 values are ranging from 0.864 to 0.873, which are relatively "High". Hence, this model effectively explains the variance in average returns for both small and large stocks.

"four-factor model"regressionresultsfor2x3market,size,valueandGHGemissionsorted, knownasCarhartGHGemissionmodel,6portfoliosareshowninTables9and10.This means Carhart's "four-factor model", including the GHG emissions factor, Forsmallstocks,thealphavaluesdecreasefrom0.008 ("Low" performance) to 0.001 ("High" performance). The model is consistent across the performance categories ("Low", "Medium", "High"), as the alpha values arequitesimilar.However,theslightly"High"eralphainthe"Medium" category(0.009)suggeststhe modelisleasteffectiveinfullyexplaining"Medium"-performingsmallstocks,thoughthedifference isminor.The "Carhart four-factor model" with the GHG emissions factor, which has positive alphas close to zero in the "Low" and "Medium" categories, effectively explains big stocks, althoughportfoliosstillearnslightlymorethanpredicted.

ModelPerformance Test

The "Gibbons,Ross,andShanken"(GRS)testfor"asset pricing models" evaluatesthemodelsability to capture expected returns and check if the model's predicted returns align with actual observed returns. In Table 14, the size-value in "Carhart four-factor model", Size Value (Value Weights), Size_Momentum(ValueWeights),Size_GHG(ValueWeights)andSize_GHG(EqualWeights) fromCarhartFourFactorwithGHGEmissionandSize_Value(ValueWeights)Size_GHG(Value Weights) and Size_GHG (Equal Weights) from Carhart GHG emission factor model are not rejected by null hypothesis. The Carhart four factor with GHGemissionmodelshowsJensen's alpha values show outperformance in GHG emission factor variations. Some negative alphas.

Table5 Results of"Carhart four-factor model" regression "(Rm−Rf,SMB, HML&WML)"

$$Rpit\text{-}Rft = \alpha + \beta\,(Rm - Rf) + s(SMB)t + h(HML)t + w(WMLt) + e\;it$$

6size_valueportfolio&6size_momentumportfolio Value weights**α** t (**α**)

	""Low""	""Medium""	""High""
"Small"	0.055	0.055	0.053
Big	0.047	0.052	0.053

	"Low"	**"Medium"**	**"High"**
"Small"	2.525	2.524	2.492
Big	2.395	2.538	2.466

Rm− Rf **t(Rm− Rf)**

	""Low""	""Medium""	""High""
"Small"	0.725	0.617	0.363
Big	-0.098	0.235	0.073

	""Low""	""Medium""	""High""
"Small"	1.384	1.200	0.762
Big	-0.299	0.464	0.192

s **t (s)**

	""Low""	""Medium""	""High""
"Small"	-0.302	-0.104	0.354
"Big"	1.318	0.493	0.985

	""Low""	""Medium""	""High""
"Small"	-0.303	-0.100	0.318
"Big"	1.454	0.683	0.928

t(h)

	"Low"	**"Medium"**	**"High"**
Small	−0.089	0.329	0.188
Big	0.993	1.500	0.512

	"Low"	**"Medium"**	**"High"**
Small	−0.087	0.321	0.170
Big	0.573	1.056	0.355

w **t(w)**

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	“Low”	“Medium”	“High”
Small	−0.043	0.044	−0.032
Big	−0.044	-0.225	−0.049

	“Low”	“Medium”	“High”
Small	−1.752	0.037	−0.910
Big	−1.693	-0.133	−1.916

R^2 Adj R^2

	“Low”	“Medium”	“High”
Small	0.869	0.868	0.869
Big	0.875	0.870	0.871

	“Low”	“Medium”	“High”
Small	0.864	0.985	0.701
Big	0.870	0.865	0.867

Source: The authors

Table6 Results of “Carhart four-factor model”regression “(Rm−Rf, SMB,HML&WML)”

$$Rpit - Rft = \alpha + \beta\,(Rm - Rf) + s(SMB)t + h(HML)t + w(WMLt) + e\ it$$

6size_valueportfolio&6size_momentumportfolio Equal weights
α t (**α**)

	“Low”	“Medium”	“High”
Small	−0.036	−0.029	−0.011
Big	−0.001	−0.044	−0.031

	“Low”	“Medium”	“High”
Small	−0.242	−0.192	−0.070
Big	−0.007	−0.282	−0.208

Rm− Rf

	“Low”	“Medium”	“High”
Small	0.082	0.112	0.110
Big	0.316	−0.126	0.159

t(Rm− Rf)

	“Low”	“Medium”	“High”
Small	0.807	0.940	0.810
Big	2.203	−0.949	1.638

s t (s)

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	"Low"	"Medium"	"High"
Small	−0.123	−0.160	−0.167
Big	−0.353	0.056	−0.184

	"Low"	"Medium"	"High"
Small	−1.351	−1.428	−1.211
Big	−2.521	0.415	−2.170

h t (h)

	"Low"	"Medium"	"High"
Small	−0.028	−0.045	−0.030
Big	−0.322	0.052	−0.142

	"Low"	"Medium"	"High"
Small	−0.644	−0.822	−0.510
Big	−2.434	0.3831	−1.824

w t (w)

	"Low"	"Medium"	"High"
Small	−0.091	−0.188	0.070
Big	−0.083	−0.139	0.001

	"Low"	"Medium"	"High"
Small	−1.395	−1.523	0.732
Big	−1.084	−0.932	0.010

R^2 Adj R^2

	"Low"	"Medium"	"High"
Small	0.495	0.499	0.509
Big	0.516	0.523	0.511

	"Low"	"Medium"	"High"
Small	0.472	0.477	0.487
Big	0.495	0.503	0.489

Source: The authors

Table 7 Resultsof "Carhart "four-factor model""withGHGemission regression(Rm−Rf, SMB, HML, WML & HgMLg)

$$Rpit - Rft = \alpha + \beta(Rm - Rf) + s(SMB)t + h(HML)t + w\ (WMLt) + g(HgMLg) + e\ it$$

6size_valueportfolio,6size_momentumportfolio&6size_GHGportfolio Value weights

α t (**α**)

	"Low"	"Medium"	"High"
Small	−0.085	−0.075	−0.068
Big	−0.074	−0.060	−0.056

	"Low"	"Medium"	"High"
Small	−1.735	−1.794	−1.837
Big	−1.796	−1.890	−1.921

Rm– Rf t(Rm-Rf)

	"Low"	"Medium"	"High"
Small	−0.214	−0.376	−0.309
Big	−0.395	−1.085	−0.391

	"Low"	"Medium"	"High"
Small	−0.210	−0.368	−0.332
Big	−0.291	−0.750	−0.447

s t (s)

	"Low"	"Medium"	"High"
Small	−0.302	−0.104	0.354
Big	1.318	0.493	0.985

	"Low"	"Medium"	"High"
Small	−0.303	−0.100	0.318
Big	1.454	0.683	0.928

h t(h)

	"Low"	"Medium"	"High"
Small	−0.036	0.350	0.234
Big	0.906	1.257	0.523

	"Low"	"Medium"	"High"
Small	−0.036	0.354	0.220
Big	0.607	1.122	0.389

w t (w)

	"Low"	"Medium"	"High"
Small	0.009	−0.033	0.010
Big	−0.022	−1.665	0.015

	"Low"	"Medium"	"High"
Small	0.258	0.034	0.226
Big	−0.734	−1.177	0.361

g t (g)

	"Low"	"Medium"	"High"
	"Low"	**"Medium"**	**"High"**
Small	0.424	3.302	4.645
Small	0.870	0.869	0.878
Big	−0.577	0.159	−3.191
Big	0.870	0.869	0.872

	"Low"	"Medium"	"High"
	"Low"	**"Medium"**	**"High"**
Small	−0.413	1.100	0.956
Small	0.864	0.864	0.873
Big	−0.348	0.281	−0.940
Big	0.873	0.864	0.867

R^2 Adj R^2

Source: The authors

Table 8 Resultsof "Carhart four-factor model" with GHGemission regression(Rm−Rf, SMB, HML, WML & HgMLg)

$$Rpit-Rft=\alpha+\beta(Rm-Rf)+s(SMB)t+h(HML)t+w\ (WMLt)+\ g(HgMLg)+e\ it$$

6size_valueportfolio,6size_momentumportfolio&6size_GHGportfolio Equal weights

α t (**α**)

	"Low"	"Medium"	"High"
Small	−0.044	−0.034	0.011
Big	0.005	0.011	−0.072

	"Low"	"Medium"	"High"
Small	−0.296	−0.220	0.071
Big	0.034	0.071	−0.486

Rm− Rf

	"Low"	"Medium"	"High"
Small	0.070	0.073	0.112
Big	0.291	−0.131	0.137

t(Rm− Rf)

	"Low"	"Medium"	"High"
Small	0.709	0.625	0.843
Big	2.079	−0.995	1.420

s t (s)

	"Low"	"Medium"	"High"
Small	−0.118	−0.129	−0.174
Big	−0.335	0.056	−0.170

	"Low"	"Medium"	"High"
Small	−1.328	−1.181	−1.290
Big	−2.455	0.413	−2.036

h t (h)

	"Low"	"Medium"	"High"
Small	−0.078	−0.082	−0.088
Big	−0.094	−0.073	−0.081

	"Low"	"Medium"	"High"
Small	−2.287	−2.252	−2.288
Big	−2.305	−1.688	−2.293

	"Low"	"Medium"	"High"
Small	−0.126	−0.141	0.095
Big	−0.071	−0.104	0.001

	"Low"	"Medium"	"High"
Small	−1.849	−0.873	0.987
Big	−0.958	−0.701	0.019

w t (w)
g t (g)

	"Low"	"Medium"	"High"
Small	−0.085	−0.107	−0.122
Big	−0.239	0.047	−0.145

	"Low"	"Medium"	"High"
Small	−0.620	−0.890	−1.216
Big	−1.851	0.334	−1.302

R^2 Adj R^2

	"Low"	"Medium"	"High"
Small	0.510	0.502	0.528
Big	0.525	0.531	0.518

	"Low"	"Medium"	"High"
Small	0.481	0.473	0.500
Big	0.497	0.503	0.489

Source: The authors

Table9 Results ofCarhart GHGemissionmodel regression(Rm– Rf,SMB, HML& HgMLg)

$$Rpit-Rft=\alpha+\beta\ (Rm- Rf)+s(SMB)t+ h(HML)t+ g\ (HgMLg)+ e\ it$$

6size_valueportfolio&6size_GHGportfolio Value weights

α t (α)

	"Low"	"Medium"	"High"
Small	0.008	0.006	0.001
Big	0.001	0.006	0.007

	"Low"	"Medium"	"High"
Small	1.837	1.853	1.885
Big	2.059	1.928	1.917

Rm– Rf

	"Low"	"Medium"	"High"
Small	0.729	0.061	0.272
Big	−0.243	−0.745	0.081

t(Rm– Rf)

	"Low"	"Medium"	"High"
Small	0.637	0.049	0.226
Big	−0.217	−0.507	0.075

s t (s)

	"Low"	"Medium"	"High"
Small	−0.777	0.435	0.056
Big	1.093	1.596	0.449

	"Low"	"Medium"	"High"
Small	−0.542	0.277	0.033
Big	0.685	1.026	0.277

h t (h)

	"Low"	"Medium"	"High"
Small	−0.095	0.322	0.174
Big	0.991	1.524	0.495

	"Low"	"Medium"	"High"
Small	−0.094	0.320	0.164
Big	0.553	1.081	0.355

g t (g)

	"Low"	"Medium"	"High"
Small	−0.424	0.302	0.645
Big	−0.577	0.159	−0.191

	"Low"	"Medium"	"High"
Small	−0.413	1.100	0.956
Big	−0.348	0.281	−0.940

R^2 Adj R^2

	"Low"	"Medium"	"High"
Small	0.869	0.872	0.878
Big	0.870	0.869	0.872

	"Low"	"Medium"	"High"
Small	0.864	0.866	0.873
Big	0.864	0.867	0.867

Source: The authors

Table10 ResultsofCarhartGHG emissionmodel regression(Rm−Rf,SMB,HML& HgMLg)

$$Rpit-Rft=\alpha+\beta\ (Rm-Rf)+s(SMB)t+h(HML)t+g\ (HgMLg)+e\ it$$

6size_valueportfolio&6size_GHGportfolio Equal weights

α t (**α**)

	"Low"	"Medium"	"High"
Small	0.007	0.009	0.008
Big	0.003	0.008	−0.011

	"Low"	"Medium"	"High"
Small	0.300	0.057	0.370
Big	0.355	0.371	−0.075

Rm− Rf

t(Rm− Rf)

	"Low"	"Medium"	"High"
Small	0.011	0.058	0.064
Big	0.252	−0.163	0.082

	"Low"	"Medium"	"High"
Small	0.108	0.462	0.462
Big	1.760	−1.141	0.802

s t (s)

	"Low"	"Medium"	"High"
Small	−0.090	−0.136	−0.152
Big	−0.322	0.064	−0.146

	"Low"	"Medium"	"High"
Small	−0.969	−1.191	−1.108
Big	−2.365	0.447	−1.689

h t(h)

	"Low"	"Medium"	"High"
Small	−0.057	−0.068	−0.065
Big	−0.093	−0.071	−0.078

	"Low"	"Medium"	"High"
Small	−1.750	−1.923	−1.722
Big	−2.300	−1.665	−2.221

g t (g)

	"Low"	"Medium"	"High"
Small	−0.079	−0.077	−0.125
Big	−0.236	0.082	−0.146

	"Low"	"Medium"	"High"
Small	−0.538	−0.610	−1.250
Big	−1.772	0.560	−1.319

	"Low"	"Medium"	"High"
Small	0.478	0.483	−0.152
Big	0.322	0.064	−0.146

	"Low"	"Medium"	"High"
Small	0.459	0.464	−1.108
Big	−2.365	0.447	−1.689

R^2 Adj R^2

Source: The authors

Table 11 Model 1 OLS regression result (with Robust SE) of "Carhart "four-factor model"" usingobservations 2012:02-2023:03 (T = 134)
Dependentvariable: RP-RF

Variable	Model1Carhart Four-Factor				
	"Coefficient"	"Std. Error"	"t-ratio"	"p-value"	
"Const"	5.81448	3.83843	1.515	0.1321	
RSMB	−1.31269	0.0630032	−20.84	<0.0001	***
RHML	−1.00261	0.00270928	−370.1	<0.0001	***
RWML	−0.369939	0.0750525	−4.929	<0.0001	***
R^2					0.047
Durbin Watson					2.073

Breusch-Pagan	0.179

Source: The authors

The OLS regression of model 1 without robust SE shows a DW statistic of 0.372 & Breusch-Pagan test result of 0.000 indicates strong evidence of heteroscedasticity and suggests considering Robust Standard Errors (SE), displayed in Table 11, to account for the issue with autocorrelation and heteroscedasticity which could bias the results.

Table12 Model2OLSregressionresultof "Carhart four-factor model" withGHGemissionusing observations 2012:02-2023:03 (T=134)

Dependentvariable: RP-RF

Variable	Model2"Carhart four-factor model"withGHGemission				
	"Coefficient"	"Std. Error"	"t-ratio"	"p-value"	
"Const"	−0.541530	0.339367	−1.596	0.1130	
RSMB	−1.32679	0.0634858	−20.90	<0.0001	***
RHML	−1.00044	0.00292417	−342.1	<0.0001	***
RWML	0.294888	0.225688	1.307	0.1937	
RHgMLg	1.06406	0.879977	1.209	<0.0001	***
R^2					0.868
Durbin Watson					2.115
BreuschPagan					0.191

Source:The authors

Table 12 reflects the OLS regression result of the "Carhart four-factor model" with GHG emission.Thetratioandp-valueindicatethatRSMBandRHMLcoefficientare"High"lystatistically significant and indicate a negative relationship between small-cap performance with RP-RF and between value stocks and RP-RF. RWML suggest that the effect of momentum on RP-RF is not consistent or strong and the p-value is <0.05 which is not statisticallysignificant.

Table 13 Model 3 OLS regression result of Carhart GHG emission factor model using observations 2012:02-2023 (T=134)

Dependentvariable: RP-RF

Variable		Model3 "Carhart GHGemission factor"			
	Coefficient	Std. Error	t-ratio	p-value	
Const	−0.627003	0.328336	−1.910	0.0584	*
RSMB	−1.35975	0.0744829	−18.26	<0.0001	***
RHML	−1.00016	0.00277715	−360.1	<0.0001	***
RHgMLg	0.360999	0.0815812	1.425	<0.0001	***
R^2					0.879
Durbin Watson					2.153
BreuschPagan					0.326

Source: The authors

The OLS regression of Carhart GHG emission factor models in Table 13 displays the statistical significance of RHgMLg (GHG) as a positive indicator to RP-RF of 0.37 approximately and t- ratio of 1.425 and p-value <0.0001 (at 1% significance level). The R^2value indicates that 87.9% variable accordingto model 3 which signs the best fitandstrongexplanatorypowerofthemodel.

Table14 GRS test,"Sharpe ratio and Jensen's Alpha"

Model	**GRS F-test**	**"GRS Pvalue"**	**"Sharpe ratio"**	**"Jensen's Alpha"**

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CarhartFourFactorModel				
Size_Value (value weights)	0.809	0.564	0.366	-0.323
Size_Value (Equal weights)	3.482	0.003	0.321	0.415
Size_Momentum(value weights)	2.377	0.032	0.528	0.345
Size_Momentum(Equal weights)	3.014	0.008	0.220	0.354
CarhartFourFactorwithGHGEmission				
Size_Value(value weights)	0.862	0.494	0.607	0.258
Size_Value (Equal weights)	2.412	0.007	0.850	0.377
Size_Momentum(value weights)	1.811	0.233	1.041	0.479
Size_Momentum(Equal weights)	1.864	0.002	0.728	0.345
Size_GHG(value weights)	1.352	0.238	0.267	-0.804
Size_GHG (Equal weights)	0.884	0.508	1.514	0.376
CarhartGHGEmissionFactormodel				
Size_Value(value weights)	0.809	0.424	0.630	0.258
Size_Value (Equal weights)	2.364	0.005	0.218	0.325
Size_GHG(value weights)	0.652	0.168	0.563	0.319
Size_GHG(Equal weights)	0.954	0.561	0.171	0.369

Source:The authors

DISCUSSION

The alternative hypothesis testing results indicate that H1 and H2 are rejected and it depicts that the Carhart Four-Factor model alone does not fully explain portfolio returns. These findings are supported by previous studies (Fama & French, 2015), (John M. Griffin, 2002), (Asness et al., 2013), (Roy & Shijin, 2018). In (Jegadeesh & Titman, 1993), support that momentum is an important factor in explaining returns but the Carhart model may fall short in certain contexts and fails to explain returns fully in all portfolio contexts. In case H3 and H4 are accepted GHG emissions significantly contribute to returns and performance evaluation outcome of the Carhart model with GHG. These results confirm the results from prior studies such as (Brandon et al., 2021), (Safiullah et al., 2022), (Bolton & Kacperczyk, 2021), (Provaty et al., 2024), (Aswani et al., 2024), (Galama & Scholtens, 2021), (Liesen et al., 2017), (Ahmad et al., 2023), (Vilkov et al., 2023). While examining the performance of the models, the Carhart Four-Factor Model with GHG emissions showed improved explanatory power (R2 of 86-87%). GHG emissions factor provides additional insight into returns, especially for small companies. These results indicate a comparable with (Kempf & Osthoff, 2007), (Davoodi et al., 2024), (Henriksson et al., 2019), (Giese et al., 2021),(Lins et al., 2017). Even though there are multiple comparable findings, there are also contradictory evidence from previous research, such as (Khandelwal et al., 2023), (Baker et al., 2018), (Sudheer Chava, 2014).

CONCLUSION

This paper applies "Carhart's four-factor model" withGHG to the"S&P BSE" Greenex Index between 2012 and 2023 to assess returns towards compare through traditional benchmarks. "Carhart four-factor model", including the "Carhart GHG emission factor" and "Carhart four-factor model", are the only ones that accept the alternative hypothesis of the GRS test, indicating they adequately explain portfolio average returns. The "Carhart four-factor model" with GHG emissions shows improved performance and "Low"er GRS test statistics, suggestingthat incorporatingGHGemissionsfactorsenhancesthemodelefficiencyforspecificportfolios.

PracticalImplication, LimitationandFurtherscopeofstudy

Investorsdemand greeninvestmentpremiumswhichdrivepremiuminvestmentforbetter returns. Adding new factors related to corporate sustainability or climate risk could give a more nuanced view of green investing. The BSE Greenex Index could be compared to global green indices like "the S&P Global Clean Energy" or the MSCI ESG Leaders Index for further research. The conduct of this study is limited to taking additional factors as GHG only. Sustainable investment analysis can further consider water usage, waste management and resource management. Hypothesis acceptance/rejection is based solely on statistical significance is a limitation that lacks consideration of economic significance and requires sensitivity analysis.

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