

1 Portfolio of Infrastructure Investments: An analysis of European

2 Infrastructure

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21 Abstract:

22 Infrastructure is receiving much attention in recent years. Investing in infrastructure is
23 particularly effective and suggested for institutional investors such as pension funds
24 due to the characteristics of infrastructure assets. However, robust analytical and
25 empirical analyses that support these investments are limited due mainly to scant
26 empirical data. In this work by collecting relevant data sets on infrastructures, we
27 address two objectives. First, we examine the significance of listed infrastructure
28 sectors and sub-sectors by assessing the investment characteristics and performance of
29 different infrastructure indexes in Europe. The aim here is to determine how an
30 effective and successful infrastructure portfolio should be constructed. Our second
31 objective is to evaluate the strategy of infrastructure investors, in other words, if the
32 investor should invest in a portfolio containing different infrastructure sectors or

33 whether it is still possible to obtain diversification benefits by investing in only a single
34 infrastructure sector.

35

36 **1. Introduction**

37 Since the early 2000s, firstly due to the availability of ‘cheap’ debt and then due to the
38 need for an alternative asset class after the financial crisis, private investors have
39 steadily become interested in infrastructure¹ investments in Europe, Asia and the
40 United States (Inderst 2009). This asset class has garnered particular attention recently
41 not only because of the distinctive investment characteristics of the sector but also in
42 response to the recent global financial crisis, which have compelled governments to
43 turn to infrastructure investments for economic recovery (RREEF 2011). However, for
44 instance in Europe despite the willingness of many governments to invest in
45 infrastructure as a means of boosting their economies, budgetary constraints imposed
46 by the financial recession on European governments have restrained their enthusiasms
47 towards this investment class (Gomez and Vassalo 2014).

48

49 Infrastructure investments are not only on the agenda of governments but also private
50 investors are examining these investments with great interest. A study made by Preqin
51 (2013) shows that institutional investors, such as pension funds, will continue to
52 allocate globally, significant amounts of capital to infrastructure assets, thereby gaining
53 exposure to European infrastructure assets in particular. Their analysis demonstrates
54 that starting from 2010, European fundraising levels have doubled year-on-year (Preqin
55 2013) and that 42% of infrastructure funds are allocated in European infrastructure

¹ Infrastructure is often split into two categories: economic and social infrastructure. Economic infrastructure consists of transport services (rail, ports, roads and airports) and other services, such as utilities, energy and telecommunications (Russ et al. 2010), whereas social infrastructure refers to public assets such as hospitals, schools and prisons.

56 (Preqin 2014). We can observe that the annual European infrastructure deal flow has
57 risen significantly due to secure political, regulatory and economic conditions, and to
58 the existence of numerous investible assets with uncorrelated and stable returns (Preqin
59 2013).

60

61 Despite the increased demand for European assets, there are limited specific researches
62 in this area, mainly due to scant empirical data. Most of the existing study concentrates
63 on global infrastructure (RREEF Research 2009) and on the Australian infrastructure
64 market, as it is the most mature market (e.g., Finkenzeller et al. 2010; Peng and Newell
65 2007; Newell et al. 2011). To date, the research dedicated to the European infrastructure
66 class (Oyedele 2013; RREEF Research 2010; Newell and Peng 2007) often examines
67 listed infrastructure as a whole with limited scrutiny on the economic characteristics of
68 this investment class rather than gives thoroughgoing attention to specific infrastructure
69 sectors. Moreover, most of the aforementioned research assumes that the infrastructure
70 sectors have the same distinctive and attractive investment characteristics; nonetheless
71 there is no specific empirical evidence to support such assertion. Infrastructure is a new
72 vast asset class consisting of many different sectors, each with its own features and
73 historical performance. As Hall et al. (2014) argue one of the major challenges in
74 understanding the long-term performance of infrastructure is the complexity of the
75 sector. Addressing the present knowledge gap will therefore be our objective in this
76 work.

77

78 Against this background, the objectives of this analysis are twofold. Our first research
79 objective is to understand the investment profile of each infrastructure sector and sub-
80 sector. Our second and most important aim is to analyze the significance of this

81 sectorial and sub-sectorial differentiation in investor's investments. To address the first
82 objective, we show how investment characteristics of many different European
83 infrastructure sectors and sub-sectors compare with those of more traditional assets in
84 order to conduct a robust analytical examination of the investment profile of different
85 infrastructure sectors and sub-sectors. In order to address our second aim we examine
86 whether it is beneficial for an investor to build a portfolio of different infrastructure
87 sectors or if it is still possible to obtain diversification benefits by investing in one sector
88 only. We assert that proving the optimality of portfolios, even when investments are
89 focused in a single sector, is important, as in that way the manager of the portfolio will
90 still be able to diversify and yet will also develop a deeper understanding of the behavior
91 of the sector.

92

93 The paper is structured in the following way: Section 2 reviews the available literature.
94 Section 3 describes the data and methodology used in the present research. A discussion
95 of our analysis results is provided in Section 4 and 5, with conclusions drawn in Section
96 6.

97

98 **2. Literature Review**

99 One key characteristic of infrastructure assets which distinguishes them from all other
100 traditional assets is that they usually operate as a natural monopoly. Under a natural
101 monopoly model, efficient cost optimisation occurs if there is only one firm responsible
102 for the entire output of an industry (Mackay-Fisher 2012). As such, infrastructure assets
103 usually have one or more of the following characteristics: high barriers to entry,
104 economies of scale, inelastic demand, and long-duration (Inderst 2009). These

105 characteristics convey many attractive investment features to the infrastructure assets,
106 including:

- 107 • secure stable cash flows,
- 108 • low correlation to other assets,
- 109 • inflation hedging properties, and
- 110 • low correlation with macroeconomic conditions.

111 As a result of the strong interest in infrastructure, there is a range of infrastructure
112 projects, listed infrastructure funds, companies, and unlisted infrastructure funds from
113 which to examine the investment characteristics of this asset class (Oyedele 2013; Peng
114 and Newell 2007). As mentioned above, research is mainly focused on the performance
115 of the global and Australian infrastructure market.

116

117 According to a performance survey of 100 European Pension Schemes, the expectation
118 of returns for infrastructure assets over a period of 10 years are annualised at 9.5%,
119 lower than private equity but higher than stocks, bonds and cash (Inderst 2009). The
120 asset-liability model of Morgan Stanley Investment Management (2007) compared five
121 different asset classes and found that infrastructure falls behind bonds in terms of
122 volatility and behind private equity in terms of returns. Rickards (2008) also compared
123 the performance of infrastructure assets to equities, emerging markets and cash over a
124 period of 12 years. His results indicated that, on a risk-adjusted return basis,
125 infrastructure outperforms other assets, and he further confirmed that infrastructure's
126 inherent characteristics yield better returns and lower volatility.

127

128 The first academic study on the performance of infrastructure funds was carried out by
129 Peng and Newell (2007) using both listed and unlisted infrastructure funds in Australia.

130 Australia has a relevant and available data on infrastructure due to its significant
131 experience with unlisted infrastructure funds. The authors compared the performance
132 of 19 unlisted infrastructure funds, 16 listed infrastructure funds and 16 listed
133 infrastructure companies. They evaluated the performance of funds using returns
134 obtained by UBS for listed infrastructure funds and listed infrastructure companies; and
135 for the unlisted infrastructure funds they used an equally weighted index of 5 out 19
136 major Australian unlisted funds. For the period between Q3. 1995–Q2. 2006, Peng and
137 Newell found average annual returns to be 22.4% for listed infrastructure and 14.1%
138 for unlisted infrastructure. Higher returns of listed infrastructure came, however, at the
139 expense of much higher volatility (16.03%) than all other assets. Whereas unlisted
140 infrastructure fund performance achieved higher average annual returns from Listed
141 Property Trusts (LPTs), Real Estate Investment Trusts (REITs), stocks, direct property,
142 and bonds. The annual volatility of unlisted infrastructure funds was 5.83%, higher than
143 direct property and bonds, but with lower volatility than (LPTs) and stocks.

144

145 Another interesting study was conducted in 2010 by Colonial First State Global Asset
146 Management (CFS-GAM) which confirmed that listed infrastructure shows higher
147 returns for a 10-year period up to 2006 than unlisted infrastructure, direct property and
148 bonds, but also shows higher volatility. However, the results were not consistent when
149 compared to a shorter 3 or 5-year period (Beeferman 2008). A more recent study carried
150 out by the CFS (2010), using their own index of 5 unlisted infrastructure funds in
151 Australia from 2000-2010, demonstrates that volatility and good risk-adjusted returns
152 compare favorably to other assets.

153

154 At this point, we need to notice that one important characteristic of infrastructure assets
155 is that they have low dependence on macroeconomic conditions, thus guaranteeing the
156 resilience of infrastructure returns during periods of low economic activity. Beeferman
157 (2008,) as in the study of Peng and Newell (2007), when calculating the Sharp ratio,
158 has shown that unlisted infrastructure had the highest Sharp ratio of all other asset
159 classes, with the exception of direct property. Newell et al. (2011) in order to account
160 for the effects of the financial crisis, focus on the same unlisted infrastructure funds as
161 CFS study (2010) and Listed infrastructure but extended the dates over a 14-year
162 period, from Q3. 1995 to Q2. 2009. Compared to previous studies, all annual returns
163 were lower for all assets except unlisted infrastructure, which remained unchanged at
164 14.1% with a volatility of 6.27%. Listed infrastructure was the third best performing
165 asset after unlisted infrastructure and direct property with an annual return of 16.7%
166 and volatility 24.6%. During the financial crisis, specifically during the period between
167 Q2. 2007 and Q2. 2009, all returns from asset classes were negative except for unlisted
168 infrastructure funds and bonds. Importantly, unlisted infrastructure funds showed the
169 highest Sharp ratio of 0.32 while bonds had a Sharp ratio of 0.15. The study of CFS
170 (2010) also confirms this conclusion. Their index of 5 Australian unlisted funds was
171 less affected by the financial crisis, thereby verifying that unlisted infrastructure
172 performance is robust during an economic downturn.

173

174 Another pertinent observation is related to the correlation with other assets because
175 diversification can be achieved by investing in assets with a low correlation of returns.
176 The analysis of correlation of returns is heavily constrained by the lack of available
177 data so most studies use listed infrastructure indices. For instance, a study made by
178 Deutsche Bank asset management unit RREEF (2007) evaluates the performance and

179 correlations of global returns for 10 years among alternative assets and traditional assets
180 analyzing UBS listed infrastructure. The authors define alternative assets as illiquid
181 assets that have a limited investment history, they are uncommon to use in portfolios
182 and they require specialized manager knowledge. The results show that listed
183 infrastructure has a negative correlation with bonds but it moves with general stock
184 market volatility which shows a moderate correlation between listed infrastructure
185 funds and stocks. It is interesting that listed infrastructure shows higher correlation with
186 other assets compared to unlisted infrastructure. For instance, Peng and Newell (2007)
187 estimate that listed infrastructure had a correlation of 0.21 and 0.38 with equities and
188 bonds respectively, but a correlation of 0.03 with private equity; whereas, unlisted
189 infrastructure has lower correlations with equities and bonds of 0.06 and 0.17
190 respectively, but a higher correlation of 0.26 with direct property.

191

192 The implication of these studies is that infrastructure assets can be used as a shock
193 absorber within a portfolio. Since infrastructure moves independently, it can offer
194 moderate to high returns at times when other assets' returns are decreasing. According
195 to Rickards (2008), private investors would benefit from investing in infrastructure.
196 Given these low correlation results, some analysts have attempted to identify whether
197 including infrastructure assets in a portfolio will lead to a shift in the efficient frontier,
198 giving better risk-return combinations of investment portfolios. In a CSAM (2010)
199 study, results indeed indicate that adding 5% of listed infrastructure to an institutional
200 pension portfolio of 43% equities, 24% fixed income, and 33% alternatives, would keep
201 the return of the portfolio the same 8.8% but it reduces the target risk from 11.7% to
202 11.4%. Similarly, CFS (2010) shows that adding 5% of unlisted infrastructure increases
203 the portfolio return by only 0.1% but decreases the risk of the portfolio by 0.5%.

204 Idzorek and Armstrong (2009) carry out several historical portfolio Markowitz
205 optimizations in addition to a forward-looking optimization, by using several CAPM
206 assumptions and they demonstrate that optimal allocation for infrastructure is between
207 0 and 6%. Finkezeller et al. (2010) by using historical returns and implementing a
208 mean-semi variance approach, calculate the optimal infrastructure allocation at
209 different risk levels. They conclude that low risk investors should include unlisted
210 infrastructure in their portfolios whereas high risk investors should include listed
211 infrastructure.

212

213 However, as for now research on the European infrastructure market is limited. For
214 instance, in 2010 the RREEF study on the performance of European listed infrastructure
215 assets. The indexes used are UBS Developed Infrastructure & Utilities Europe, UBS
216 Developed Utilities infrastructure, UBS Developed Infrastructure Europe, and Dow
217 Jones and Brookfield Infrastructure Europe. The study shows that UBS Infrastructure-
218 only index has the highest return among other asset classes such as stocks, bonds, real
219 estate and private equity. Oyedele et al. (2013) also examine the performance of listed
220 infrastructure over a 10-year period (2001-2010) as well as the significance of listed
221 infrastructure in a mixed-asset portfolio. The work of Oyedele et al. is one of the few
222 studies that also presents some sub-sector analysis performance, as they test the
223 performance of UBS indexes on toll roads, airports, ports, power generation, integrated
224 utilities and integrated regulated utilities. Results of the research indicates that
225 European infrastructure showed an attractive annualized return and an acceptable
226 volatility; and it outperformed more traditional assets such as European stocks and
227 European REITs but performed poorly compared to European bonds. Oyedele et al.
228 (2013) examines the performance of infrastructure during the financial crisis period and

229 in so doing he considers differentiation component among the various infrastructure
230 sub-sectors, such as ports. The results show that infrastructure had negative annualized
231 returns and high volatility but the infrastructure sub-sector has an overall better
232 performance of the infrastructure. The portfolio results demonstrate that infrastructure
233 plays a significant role in the optimality of mixed asset portfolios, the incurred benefits
234 however, are more due to enhancing returns rather than reducing risks.

235

236 We can surmise from the literature review that a gap in the literature with regard to the
237 behavior of the different infrastructure sectors and sub-sectors needs to be addressed.
238 In the next sections we will address our two objectives. In so doing, to address our first
239 objective, we assess the investment characteristics and performance of infrastructure
240 indexes in Europe from 2003-2013 for the sector analysis and from 2004-2013 for the
241 sub-sector analysis. Additionally, to address our second objective we examine whether
242 the private sector is better off by investing in an infrastructure portfolio containing a
243 mix of infrastructure sectors or if it still obtains diversification benefits by investing in
244 one specific sector.

245

246 **3. Data and Research Methodology**

247 In order to address our two objectives, we have collected data from Thomson Reuters
248 Database. The data include historical time series of monthly returns of European indices
249 over a time span of 11 years (2003-2013) for the infrastructure sector analysis, and
250 weekly returns of European indices over a 10-year time span for the sub-sector analysis
251 (2004-2013). For the sector analysis the assets included are Thomson Reuters European
252 indices in Energy, Utilities, Transport, Telecommunications, Government Bonds, Real
253 Estate, and Stocks. For the sub-sector analysis we use the following listed European

254 sub-sectors indices: Thomson Reuters Europe Ports Index, UBS Europe Toll Roads
255 Index, UBS Europe Airport Index, Europe Total Market Electricity Index, Thomson
256 Reuters Europe Fossil Fuels Energy Index, MSCI European Power and Electricity
257 Index, Thomson Reuters Renewable Energy Index, and Thomson Reuters European
258 Natural Gas Index. Risk free monthly returns from the same period are collected from
259 the Kenneth R. French Data Library in order to calculate the Sharp Index of each asset.
260 The risk free assets used are Treasury monthly T-bills.

261

262 The analysis of the European infrastructure asset performance represents our first
263 objective and we develop this analysis on the basis of three aspects. Firstly, we calculate
264 the annualized return, annualized volatility and Sharp Index of each index for the whole
265 period (for the sector analysis from Q1. 2003 to Q4. 2013 and for the sub-sector analysis
266 from Q1. 2004 to Q4. 2014). These three measures are used to compare the performance
267 among the different assets over the long-term.

268

269 The Sharp Index is calculated by the following formula:

270
$$\text{Sharp Index} = \frac{\text{Return}_i - \text{Return}_{R_f}}{SD_i}$$

271 where:

272 Return_i = Return of asset i .

273 Return_{R_f} = The return of a risk free asset (in this research Treasury monthly T-bills
274 are used).

275 Secondly, diversification benefits among infrastructure assets as well as with other
276 traditional assets (e.g., Stocks, Real Estate and Government Bonds) are evaluated based
277 on the assets' returns matrix correlation. Lastly, since the period examined is interesting
278 as it covers the period of the recent financial crisis, as a last performance test we

279 contract our dataset from Q4. 2007 to Q2. 2009 to cover only the years of the financial
280 crisis. The annualised return, annualised volatility and Sharp Index are re-calculated for
281 this 3-year period in order to examine the robustness of listed infrastructure sectors and
282 sub-sectors.

283

284 For the second objective of this paper, i.e. to confirm the best way to construct a
285 portfolio that invests in infrastructure, a portfolio historical analysis is performed using
286 the standard Markowitz (1952,1959) mean-variance portfolio optimisation technique
287 as in Oyedele (2013).

288

289 The return of the portfolio is calculated as follows:

290 • $Return_{portfolio} = \sum_1^n w_i * r_i$

291 where:

292 w_i = Weight of i th/individual security or asset in portfolio

293 r_i = Return of individual security

294 And the variance of the portfolio is calculated by:

295 • $Variance_{portfolio} = \sum_i^n w_i^2 * SD_{ij} + 2 \sum_{j=1}^n \sum_{i=1}^n w_i w_j r_{ij} SD_i SD_j$ for $i \neq j$

296 Where:

297 • $Variance_{portfolio} = var_p$

298 • $SD_p = \sqrt{var_p}$

299 • r_{ij} = Correlation coefficient between the i th and j th variables

300 • SD_{ij} = Covariance of the i th and j th variables

301 • SD_i = Standard deviation of the i th variable

302 After the recent financial crisis, tail-risk analysis has proved to be of vital test to
303 evaluate investors' portfolio risk. For this reason we also estimate the Mean-
304 Conditional Value at Risk (M-CVaR) optimization (Bianchi et al., 2014). The results
305 of the M-(CVaR) optimization are then compared with the Mean-Variance framework
306 to check their robustness. One of the arguments against Markowitz (1952,1959)
307 approach is that the Mean-Variance portfolio measures the risk of the portfolio as the
308 standard deviation; however, this is only valid when the returns are normally
309 distributed. For this reason, we also undertake a second portfolio optimization
310 technique, the M-CVaR portfolio, which uses simulations that do not necessary assume
311 that the distribution of the data is normal. The M-CVaR calculates the highest returns
312 you can obtain for a given level of CVaR at the 95% confidence level.

313

314 The $VaR_\alpha(x)$ for portfolio x , means that with a $(1 - \alpha)$ probability, the returns will not
315 fall below this level. The conditional value at risk, which is also known as expected
316 shortfall, is the expected loss of the portfolio returns above the $VaR_\alpha(x)$. Following
317 Rockafellar and Uryaser (2000,2002):

318

319 The conditional value-at-risk for a portfolio $x \in X$, is defined as

320 •
$$CVaR_\alpha(x) = \frac{1}{1-\alpha} \int_{f(x,y) \geq VaR_\alpha(x)} f(x,y)p(y)dy,$$

321 where

322 • α is the probability level such that $0 < \alpha < 1$. In this study the probability level
323 is 0.95.

324 • $f(x,y)$ is the loss function for a portfolio of x and asset return y .

325 • $p(y)$ is the probability density function for asset return y .

326 VaR_α is the value-at-risk of portfolio x at probability level α .

327 The value-at-risk is defined as

328 • $VaR_{\alpha}(x) = \min\{\gamma: \Pr[f(x, Y) \leq \gamma] \geq \alpha\}$.

329 The results of the two optimizations are compared in two ways:

- 330 • We convert the risk proxies to be able to compare the two portfolios. Using the
331 CVaR portfolio weights we calculate the mean-variance risk of the 10 M-CVaR
332 efficient frontier portfolios. This will enable us to compare the efficient
333 frontiers of both optimisations and observe any differences.
- 334 • By using area plots we visualise the weights of both the mean-variance and the
335 M-CVaR and we compare the weights of the chosen assets.

336 In order to examine how it is most beneficial to construct a portfolio with infrastructure
337 investments, we carry out two different assessments. We first evaluate the significance
338 of European infrastructure in traditional portfolios and then verify whether an investor
339 can still obtain diversification benefits by focusing on a single sector only. We consider
340 two different sectors: Transport, which we identify as a stable sector, and Energy which
341 due to the present innovative but disruptive energy technology we describe as relatively
342 unstable sector, and thus it has less attractive financial performance. We use the
343 GAMS modelling tool to conduct the Mean-Variance optimisations while, the
344 Conditional Value-at-Risk Portfolio Optimisation is estimated in Matlab.

345

346 We set out to optimise the following portfolios:

- 347 - Portfolio 1 includes only European traditional assets (Stocks, Real Estate and
348 Government Bonds).
- 349 - Portfolio 2 includes the same assets as portfolio 1 plus the addition of all
350 infrastructure sectors.

351 - Portfolio 3 specialises only in transport sub-sector assets (Airports, Ports and Toll
352 Roads) within a traditional portfolio.

353 - Portfolio 4 specialises only in the energy sub-sector assets (Natural Gas,
354 Electricity, Fossil Fuels, and Renewable Energy) within a traditional portfolio
355 .

356 **4. Results:** performance analysis of different infrastructure sectors and sub-sectors

357 In this section we address our objectives:

358 • Performance analysis of different infrastructure sectors and sub-sectors

359 For the first objective, performance analysis of different infrastructure sectors and sub-
360 sectors, the analysis is divided in two: the sectorial analysis which involves the
361 examination of the performance of four different infrastructure sectors (Energy,
362 Telecommunications, Utilities, and Transport) among traditional assets (Stocks, Real
363 Estate and Government Bonds), and the second part of the analysis which repeats the
364 same performance tests but concentrates specifically on the components of two
365 infrastructure sectors (Energy and Transport). In the second analysis we examine the
366 performance of Natural Gas, Electricity, Fossil Fuels, and Renewable Energy when
367 focussing only on the Energy sector, and the performance of Airports, Ports and Toll
368 Roads when focusing only on the Transport sector. In the sub-sector studies we
369 compare infrastructure assets with the same traditional assets as in the sector analysis
370 (Stocks, Real Estate and Government Bonds). For both analyses the results of the whole
371 dataset are presented first, in order to examine and compare the long-term historic
372 behavior of the assets. We then examine the contracted dataset in order to verify the
373 robustness of the assets during a financial crisis. Lastly, we scrutinize the diversification
374 benefits among the different assets by calculating the inter-correlation matrix for each
375 analysis.

376

377 4.1 *European Infrastructure sector performance analysis*

378 Table 1 shows the performance of European assets for the period 2003-2013. The four
379 listed infrastructure sectors show significant variation in their performance, proving
380 that infrastructure should not be treated as a singular asset, and that close attention
381 should be paid to the behavior and historical performance of infrastructure's individual
382 sectors.

383

384 As can be seen in Table 1, Transport shows a strong performance over the whole sample
385 period, with a return of 9.35% and volatility at 23.81%. It is the best performing
386 infrastructure asset, with a Sharp Index of 0.334. This is not surprising, as European
387 transport is a very stable sector. Energy instead shows the worst performance of all
388 infrastructure assets, with an annual return of 4.76% and annual volatility of 21.86%
389 resulting in a Sharp Index of 0.153. When comparing the performance of all
390 infrastructure assets with other traditional assets we can conclude that all infrastructure-
391 listed sectors (Energy, Telecommunications, Utilities, and Transport) perform better
392 than Stocks, as illustrated by a higher Sharp Index and they are also less volatile than
393 Real Estate assets. However, Government Bonds show a higher Sharp Index than all of
394 the infrastructure assets.

395

396 **Table 1.** Historical performance analysis of European Infrastructure sectors for
397 period Q1. 2003–Q4. 2013.

European Listed Asset	Annualised Return	Annualised Volatility	Sharp Index	Rank
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Energy	4.76%	21.86%	0.153	6
Telecoms	5.24%	19.21%	0.199	5
Utilities	5.96%	20.74%	0.220	3
Transport	9.35%	23.81%	0.334	2
Stocks	2.55%	18.19%	0.063	7
Real Estate	6.56%	24.47%	0.210	4
Government Bonds	5.46%	10.33%	0.392	1

398

399 *4.2 European Infrastructure sector performance during the financial crisis*

400 As mentioned above, our time period is particularly interesting in that it captures the
401 effects of the recent financial crisis. To allow us to isolate the effect of the financial
402 crisis, and to compare the robustness of listed infrastructure sectors in recessions, we
403 contract our dataset to the crisis period (Q4. 2007–Q2. 2009).

404

405 The results of the annualised return, annualised volatility and Sharp Index for the period
406 of the crisis are presented in Table 2. From our results we can conclude that all assets,
407 except Government Bonds, were severely affected by the crisis. However, all listed
408 infrastructure sectors were affected less negatively than Stocks and Real Estate, as all
409 infrastructure assets have a higher Sharp Index than Stocks and Real Estate.

410

411 **Table 2.** European Infrastructure sector performance analysis during the financial crisis
 412 Q4. 2007–Q2. 2009

European Listed Asset	Annualised Return	Volatility	Sharp Index	Rank
Energy	-25.4%	30.4%	- 0.856	3
Telecoms	-30.0%	24.6%	-1.24	5
Utilities	-30.3%	31.2%	-0.992	4
Transport	-28.2%	35.1%	-0.822	2
Stocks	-41.3%	30.6%	-1.37	6
Real Estate	-53.9%	37.8%	-1.44	7
Government Bonds	4.22%	14.4%	0.247	1

413

414 *4.3 Diversification Benefits among assets*

415 According to Hall et al. (2014), there is little tradition of thinking cross-sectorally about
 416 infrastructure system performance, and this prevents us from understanding the long-
 417 term performance of infrastructure. Nevertheless, by calculating the correlation among
 418 the monthly returns of all assets, we are able to evaluate if there are any diversification
 419 benefits among the different listed infrastructure sectors and also between the different
 420 infra-sectors and other traditional assets.

421

422 The results of the cross asset correlation matrix presented in Table 3 indicate that
 423 infrastructure sectors are highly correlated. An explanation of this is given by Hall et
 424 al. (2014, p.11), who assert that demand for infrastructure is highly correlated due to
 425 the “final demand associated with population and economic growth and because of
 426 intermediated demands among infrastructure sectors.” For example, a change in
 427 demand for electric vehicles would imply a change in demand for the energy sector.

428 This high correlation among the different listed infrastructure sectors proves that there

429 is no benefit gained from constructing a portfolio that invests only in different listed
 430 infrastructure sectors.

431 All of the listed infrastructure sectors in the table show high correlation with traditional
 432 assets as well. The high correlation with Stocks is consistent with the literature, which
 433 is not surprising, because in the present study we use indices based on publicly-traded
 434 infrastructure companies (Inderst 2009); therefore, in this analysis the low correlation
 435 with more traditional assets is not confirmed.

436

437 **Table 3.** Cross asset correlation matrix for monthly returns Q1. 2003–Q4. 2013

	<i>Energy</i>	<i>Telecoms</i>	<i>Utilities</i>	<i>Transport</i>	<i>Stocks</i>	<i>Real Estate</i>	<i>Government Bonds</i>
Energy	1						
Telecoms	0.693	1					
Utilities	0.776	0.824	1				
Transport	0.720	0.772	0.845	1			
Stocks	0.727	0.558	0.664	0.610	1		
Real Estate	0.637	0.683	0.792	0.760	0.641	1	
Government Bonds	0.601	0.709	0.707	0.665	0.206	0.644	1

438

439 4.4 Robustness Analysis

440 To avoid bias, a second index was selected for all traditional assets (Stocks, Real Estate
 441 and Government Bonds) as a control in order to check if the obtained results are index-
 442 specific. Table 4 shows the performance of the control indexes over the entire dataset.

443

444 **Table 4.** Control index historical performance analysis for Q1. 2003–Q4. 2013

European Listed Asset	Annualised Return	Volatility	Sharp Index	Rank
Stocks	3.05%	14.26%	0.115	7
Real Estate	6.04%	23.46%	0.197	4
Government Bonds	2.65%	7.28%	0.170	5

445

446 Nearly all of our conclusions are again confirmed in the robustness analysis. All
447 infrastructure sectors perform better than Stocks, and all infrastructure sectors, except
448 Transport are less volatile than Real Estate. In addition, all infrastructure sectors except
449 Energy have a higher Sharp Index than Real Estate. Government Bonds are still the less
450 volatile asset, however the control index that was used for Government Bonds shows a
451 much lower return. Thus, in the robustness analysis, Government Bonds are not the best
452 performing asset; they are outperformed by all infrastructure assets apart from Energy.
453

454 **Table 5.** Control index cross asset correlation matrix for monthly returns Q1. 2003–
455 Q4. 2013

	<i>Energy</i>	<i>Telecoms</i>	<i>Utilities</i>	<i>Transport</i>	<i>Stocks</i>	<i>Real Estate</i>	<i>Government Bonds</i>
Energy	1						
Telecoms	0.693	1					
Utilities	0.776	0.824	1				
Transport	0.720	0.772	0.845	1			
Stocks	0.713	0.627	0.705	0.668	1		
Real Estate	0.663	0.699	0.809	0.776	0.684	1	
Government Bonds	0.063	0.198	0.160	0.180	0.103	0.059	1

456

457 In the robustness analysis the cross asset correlation matrix is calculated and results are
458 given in Table 5. Notably, we can confirm that infrastructure assets are highly
459 correlated with Stocks and Real Estate, but we also observe low correlation with
460 Government Bonds in the robustness analysis. This finding indicates that there are
461 diversification benefits with infrastructure sectors and Government Bonds in a
462 portfolio.

463

464 *4.5 European Infrastructure sub-sector analysis*

465 We next set out to examine the differences between sub-sector assets. The sub-sectors
 466 of two different infrastructure sectors (Energy and Transport) have been chosen for our
 467 sub-sector analysis. The two sectors are particularly interesting because they behave
 468 very differently. The Energy sector is highly changeable, not only in terms of
 469 performance, but also due to an unstable regulatory framework (e.g., EU environmental
 470 regulation, national renewable energy incentives, feed-in tariffs) which results in
 471 higher political risk; whereas the Transport sector represents a relatively stable sector
 472 with a fairly stable regulatory framework.

473

474 The results of the long-term performance of the Energy sector are presented in Table 6.
 475 In the European Energy's sub-sector performance analysis we notice that Electricity
 476 was the best performing asset over the period examined, with a Sharp Index of 0.258.
 477 However, Fossil Fuels and Renewable Energy performed the worst of all other sub-
 478 sectors, with Sharp Indexes of 0.036 and 0.007, respectively. When we compare them
 479 to the traditional assets, we observe that all Energy sub-sectors, apart from Renewable
 480 Energy, show lower volatility than Real Estate. But Government Bonds have the lowest
 481 volatility of all of the assets.

482

483 **Table 6.** European Infrastructure Energy sub-sector historical performance analysis
 484 for Q1. 2004–Q4. 2013.

European Listed Asset	Annualised Return	Annualised Volatility	Sharp Index	Performance Rank
Natural Gas	5.27%	18.03%	0.200	3
Electricity	6.74%	19.72%	0.258	1
Fossil Fuels	2.62%	26.76%	0.036	6

Renewable Energy	1.89%	33.82%	0.007	7
Stocks	3.65%	19.69%	0.101	4
Real Estate	3.90%	27.90%	0.080	5
Government Bonds	4.01%	10.89%	0.215	2

485

486 The Transport sub-sector analysis results are presented in Table 7. In the table we can
487 see that Ports, shown by its high Sharp Index of 0.386, is the best performing asset.

488 Airports also shows a good Sharp Index of 0.308. In contrast, the performance of Toll
489 Roads is much worse than Airports and Ports, with a Sharp Index of 0.117. This is
490 expected, as Ports and Airports not only obtain revenue from their transport services
491 but also from other services in and around airports and ports (i.e., restaurants, shops
492 and so forth). In contrast, most Toll Roads accrue all their revenue solely from transport
493 demand. Despite this observation, however, research conducted by Gomez and Vassalo
494 (2014) showed that in all European countries the revenues generated from road charges
495 exceed road expenditures, with enough money remaining to also subsidise other
496 policies.

497

498 In comparison with the more traditional assets, we observe that all of Transport's sub-
499 sectors (as with the Energy sector) show lower volatility than Real Estate. Furthermore,
500 in the Transport analysis, Government Bonds show the lowest volatility of all sectors
501 as well.

502

503 **Table 7.** European Infrastructure Transport sub-sector historical performance
504 analysis for Q1. 2004–Q4. 2013

European Listed Asset	Annualised Return	Annualised Volatility	Sharp Index	Performance Rank
Airports	7.90%	20.26%	0.308	2
Ports	11.06%	24.33%	0.386	1
Toll Roads	4.20%	21.73%	0.117	4
Stocks	3.65%	19.69%	0.101	5
Real Estate	3.90%	27.90%	0.080	6
Government Bonds	4.01%	10.89%	0.215	3

505

506 *4.6 European Infrastructure sub-sector performance during the financial crisis*

507 In this section we repeat the analysis of the previous section but with a shorter dataset
508 to capture only the period of the financial crisis. Analysis results are shown in Table 8.

509 The performance of the infrastructure sub-sectors during the years of the financial crisis
510 is consistent with the infrastructure sector results. All of the infrastructure sub-sectors
511 were less negatively affected by the financial crisis than Real Estate and Stocks. We
512 can here point up the robustness of infrastructure investments during a downturn in
513 macroeconomic conditions. However, none of the infrastructure sub-sectors was more
514 robust than Government Bonds, which consistently showed the best performance of all
515 the assets during the crisis, with a positive Sharp Index of 0.22.

516

517 **Table 8.** European Infrastructure sub-sector performance analysis during the financial
518 crisis Q4. 2007–Q2. 2009

European Listed Asset	Sharp Index
Natural Gas	-0.82
Electricity	-0.96

Fossil Fuels	-0.60
Renewable Energy	-0.85
Airports	-0.70
Ports	-1.10
Toll Roads	-1.05
Stocks	-1.09
Real Estate	-1.17
Government Bonds	0.22

519

520 *4.7 Diversification Benefits among Sub-sector assets*

521 As has been emphasised in this study, when setting out to understand the behavior of
522 infrastructure systems, it is crucial to recognize the interdependence among the
523 different infrastructure assets. In this section we assess the diversification benefits of
524 both Transport and Energy sectors in order to evaluate whether correlation benefits
525 exist in single infrastructure sectors, and if so, calculate the benefit in each sector.

526 The results for the Energy and Transport sector are presented in Tables 9 and 10,
527 respectively. Generally, we observe in both sectors high correlation among all Energy
528 and Transport infrastructure sub-sectors with Stocks and Real Estate. However, for
529 some assets we find low correlation with Government Bonds. These results are also
530 consistent with our sector robustness analysis.

531

532 In relation to the correlation among the sub-sectors, however, we observe that there is
533 indeed some low correlation within the Transport and Energy sub-sectors; this finding
534 indicates that an investor can obtain diversification benefits, even when investing only
535 in the Transport or Energy sector.

536 **Table 9.** Cross asset correlation matrix for Energy sub-sector monthly returns

537 Q1. 2004–Q4. 2013

	<i>Fossil Fuels</i>	<i>Renewable Energy</i>	<i>Natural Gas</i>	<i>Electricity</i>	<i>Stocks</i>	<i>Real Estate</i>	<i>Government Bonds</i>
Fossil Fuels	1						
Renewable Energy	0.688	1					
Natural Gas	0.559	0.475	1				
Electricity	0.726	0.722	0.523	1			
Stocks	0.797	0.729	0.488	0.825	1		
Real Estate	0.734	0.652	0.485	0.658	0.779	1	
Government Bonds	0.427	0.260	0.335	0.199	0.155	0.461	1

538

539 **Table 10.** Cross asset correlation matrix for Transport sub-sector monthly returns

540 Q1. 2004–Q4. 2013

	<i>Ports</i>	<i>Airports</i>	<i>Toll Roads</i>	<i>Stocks</i>	<i>Real Estate</i>	<i>Government Bonds</i>
Ports	1					
Airports	0.362	1				
Toll roads	0.390	0.648	1			
Stocks	0.425	0.686	0.873	1		
Real Estate	0.456	0.685	0.710	0.779	1	
Government Bonds	0.294	0.460	0.245	0.209	0.516	1

541

542 After having analyzed our first objective, we can confirm that infrastructure is
 543 comprised of many different heterogeneous assets, each with its own specific
 544 performance. As a consequence, we argue that fund managers should therefore be
 545 experts in specific sector and sub-sector elements of an infrastructure investment
 546 package in order to deeply comprehend the performance and behavior of their
 547 investments.

548

549 • **5. Results:** How to construct a portfolio of infrastructure investment

550 In this section we examine how to design an infrastructure investment portfolio,
551 objective 2; four different portfolios are therefore analyzed:

552 - Portfolio 1 includes only European traditional assets (Stocks, Real Estate and
553 Government Bonds).

554 - Portfolio 2 includes the same assets as portfolio 1 plus the addition of all
555 infrastructure sectors.

556 - Portfolio 3 specialises only in transport sub-sector assets (Airports, Ports and Toll
557 Roads) within a traditional portfolio.

558 - Portfolio 4 specialises only in the energy sub-sector assets (Natural Gas,
559 Electricity, Fossil Fuels, and Renewable Energy) within a traditional portfolio

560 The results of the four different portfolio scenarios are presented in the Mean- Variance
561 framework and then compared with the M-CVaR optimisation. In relation to objective
562 2, what is of interest to us for each scenario in the Mean-Variance Framework is
563 whether we achieve a higher Sharp Index by combining different assets instead of
564 investing only in the best performing asset of each scenario.

565

566 *5.1 European Portfolio analyses with and without infrastructure*

567 - **Portfolio 1 includes only European traditional assets**

568 By investing only in Government Bonds gives a Sharp Index of 0.392, while investing
569 only in Real Estate or only in Stocks gives a Sharp Index of 0.210 and 0.063,
570 respectively. By creating a portfolio that combines Stocks, Real Estate and Government
571 Bonds, one cannot achieve a Sharp Index higher than if one were to invest only in
572 Government Bonds; this result proves that in terms of the Sharp Index ratio, it is always
573 more beneficial to invest only in Government Bonds than to combine a portfolio of
574 different traditional assets. However, depending on the risk attitude of an investor, one

575 can combine the three traditional assets to achieve either a lower risk by accepting a
576 lower return or if more risk-loving to accept a higher risk for a higher return (Efficient
577 Portfolio Frontiers can be found in the Appendix).

578

579 - **Portfolio 2 includes the same assets as portfolio 1, plus the addition of all**
580 **listed infrastructure sectors**

581 Investing in a multi-asset portfolio that combines traditional European assets and listed
582 infrastructure sectors is clearly beneficial. As depicted in Figure 1, by including
583 infrastructure in a traditional European portfolio during the period 2003-2013 provides
584 an outward shift in the efficient frontier. The implication here is that, for the same
585 amount of risk, investors can obtain higher returns.

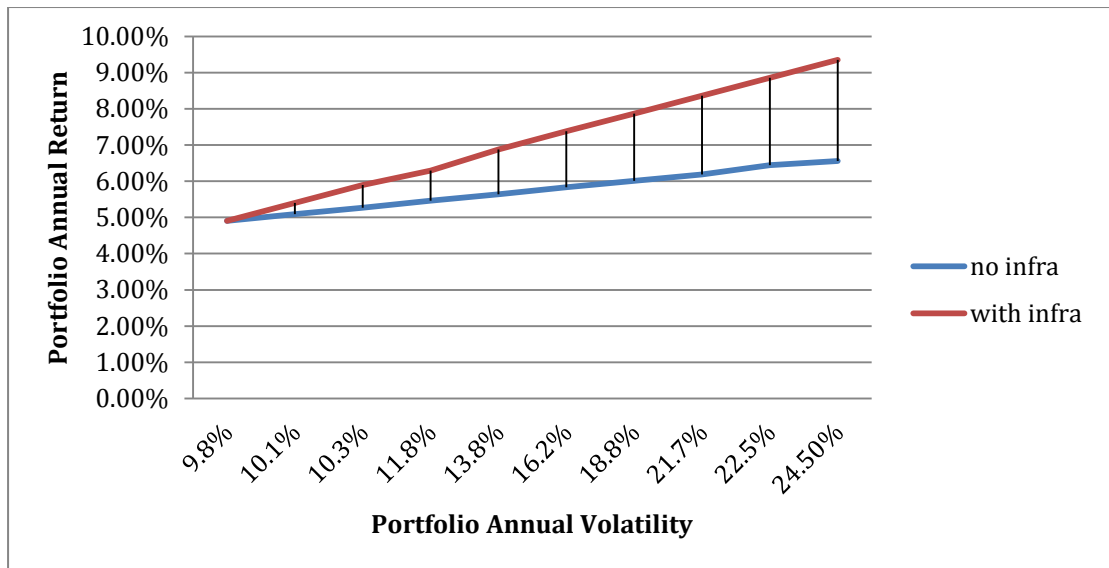
586

587 The portfolio that maximises the Sharp Index invests in Transport infrastructure and
588 Government Bonds only, thereby achieving a volatility of 12.1% and a return of 6.29%,
589 resulting in a Sharp Index of (0.402). By including infrastructure in a traditional
590 portfolio, one can obtain a higher Sharp Index than by investing in any asset on its own.

591 It is noteworthy that in none of the efficient frontiers is it optimal to create a portfolio
592 that invests in many infrastructure sectors. This finding verifies our earlier observation
593 that there are no diversification benefits between different listed infrastructure sectors.

594

595 **Figure 1.** Efficient frontiers for Portfolios 1 and 2



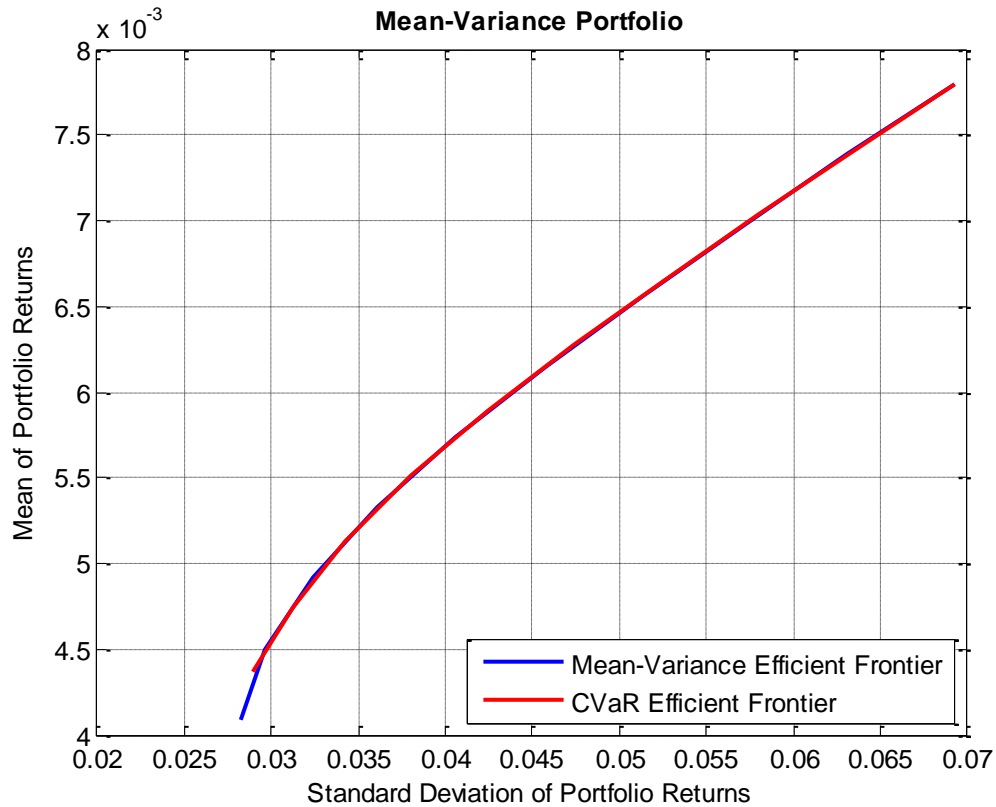
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597

598 As a sensitivity analysis, we undertook a second optimization technique, the M-CVaR
 599 optimization, to check our results (Efficient Portfolio Frontiers can be found in the
 600 Appendix). To compare the two optimizations, we calculate the monthly mean-variance
 601 risk using the weights of the M-CVaR optimization to convert from one risk to the
 602 other. This enables us to convert the efficient frontiers of the M-CVaR optimization to
 603 a mean-variance plot. Thus, as illustrated in Figure 2, we draw the Mean-Variance
 604 Portfolio Efficient Frontiers for both techniques and compare the differences. From
 605 Figure 2, one can observe that our Mean-Variance portfolio results are quite robust as
 606 the two frontiers are very similar with some differences at the lower level of the
 607 frontiers.

608

609 **Figure 2.** Efficient frontiers for the Mean-Variance and M-CVaR optimization



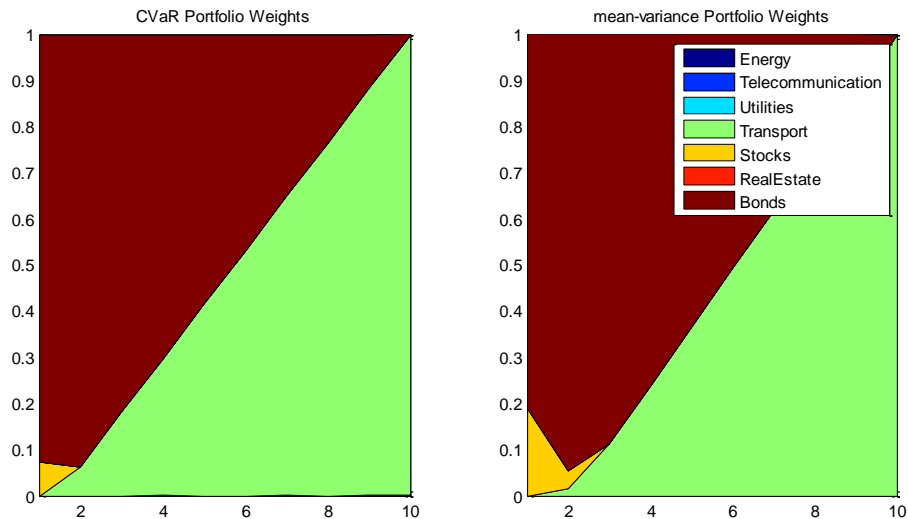
610

611 The second test that we perform is to compare the weights of the assets in the efficient
 612 portfolios of the two optimizations. Figure 3 visualizes the weights of both
 613 optimizations using area plots. The only difference observed, in the allocation of the
 614 assets between the two optimizations, is that the Mean-Variance optimization gives
 615 more weight to Stocks than the M-CVaR optimization. However, we can observe that
 616 both optimizations choose to invest in the same assets, which are Government Bonds,
 617 Transportation and Stocks. Thus, in conclusion we observe that infrastructure is a good
 618 addition to a traditional portfolio and that sectors do not mix in the construction of
 619 optimal portfolios is confirmed.

620

621 **Figure 3.** Weights Comparison for Portfolios Mean-Variance and M-CVaR
 622 optimization

623



624

625 *5.2 Sub-sector Portfolio Analysis*

626 The results of the previous portfolio scenario show that in European infrastructure
 627 investment it is not optimal to create a portfolio that invests in various infrastructure
 628 sectors. For this reason, in the third and fourth portfolios we evaluate the diversification
 629 benefits that exist by investing in a single infrastructure sector alone. As mentioned
 630 above, we have chosen to focus on the Energy and Transport sectors because we are
 631 interested in detecting the difference between investing only in a stable sector, such as
 632 Transport (where political risks are fewer) compared with the relatively new and
 633 unstable Energy sector.

634

- 635 - **Portfolio 3 specialises only in energy sub-sector assets (Natural Gas,**
- 636 **Electricity, Fossil Fuels, Renewable Energy)**

637

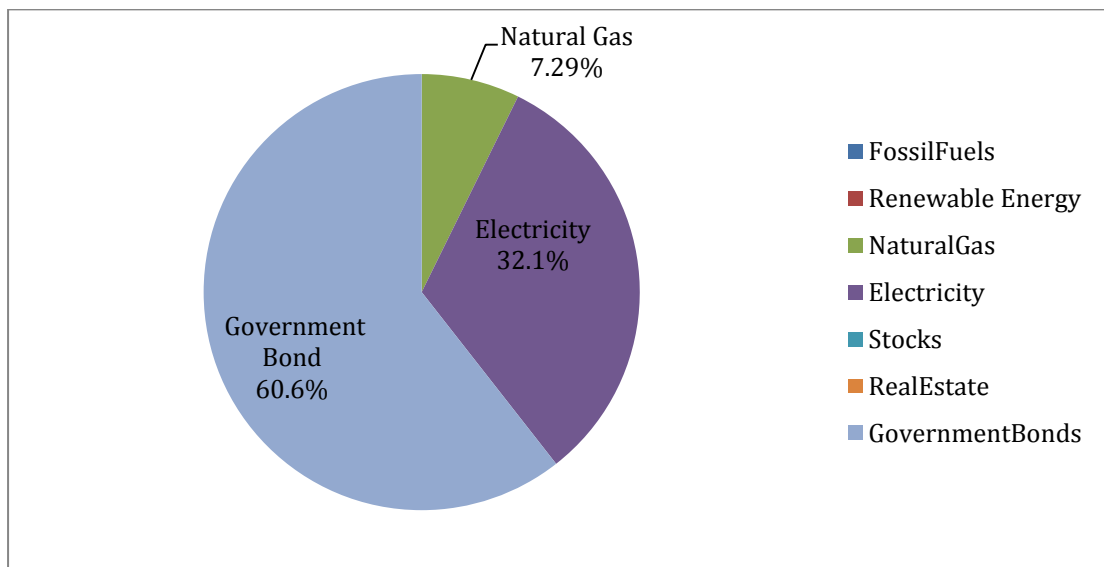
638 For the third scenario we construct a portfolio, which includes only Energy sub-sector
 639 assets within a traditional portfolio.

640

641 As we have seen in the correlation analysis, there are modest diversification benefits in
642 the Energy sector. The portfolio that maximises the Sharp Index, as can be seen by
643 Figure 4, invests 60.6% in Government Bonds, 32.1% in Electricity, and 7.29% in
644 Natural Gas. The highest Sharp Index achieved is 0.311 which is higher than the Sharp
645 Index obtained by investing in any single asset. The optimal portfolio annual return is
646 5.02% and the annual volatility is 10.8%. We observe that sectors such as Renewable
647 Energy and Fossil Fuels are not included in the optimal portfolio; this observation may
648 be because certain sectors are over-valued by the market. However, there are many
649 possible explanations for the exclusion of Renewable Energy and Fossil Fuels, such as
650 government intervention or the ethics and values of the individual fund.

651

652 **Figure 4.** Optimal Portfolio in the Optimisation of the Energy sector



653

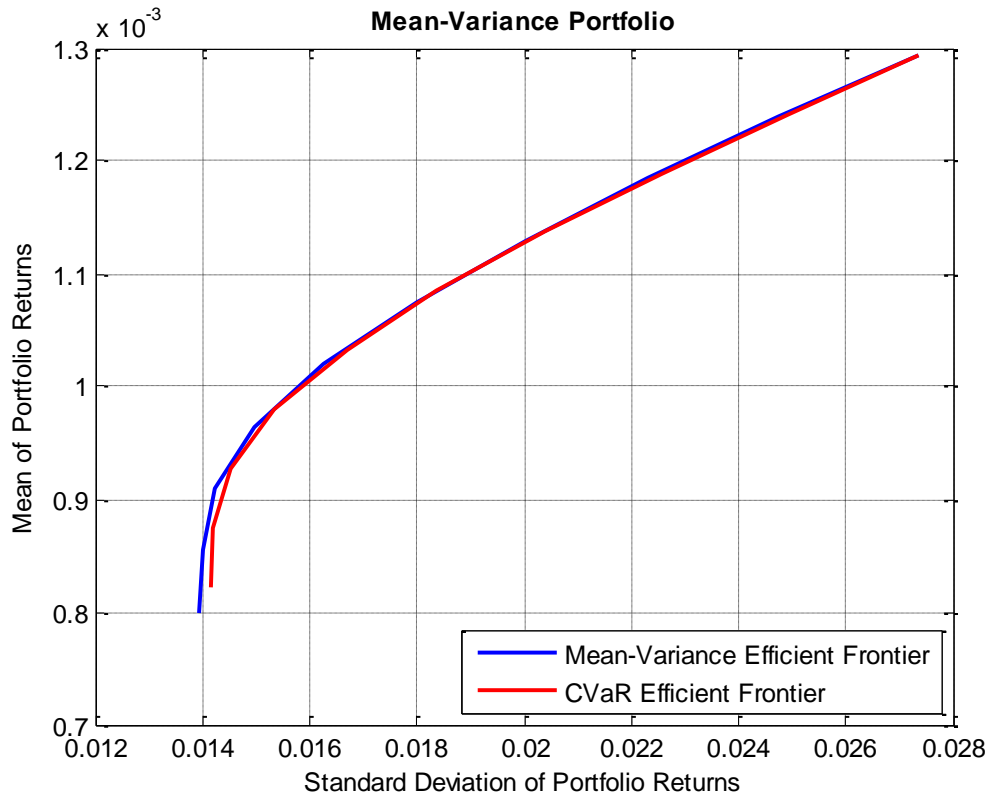
654 To validate the results above, Figure 5 shows the comparison of the weekly mean
655 variance efficient frontiers of the Mean-Variance Portfolio and the M-CVaR
656 optimisation. The Figure illustrates that some small differences exist between the two
657 optimizations, and this holds especially true for lower levels of portfolio returns.

658 Generally, however, we can observe from the Figure that the results are significantly
659 robust.

660

661 **Figure 5.** Efficient frontiers for Portfolios Mean-Variance and M-CVaR optimization

662



663

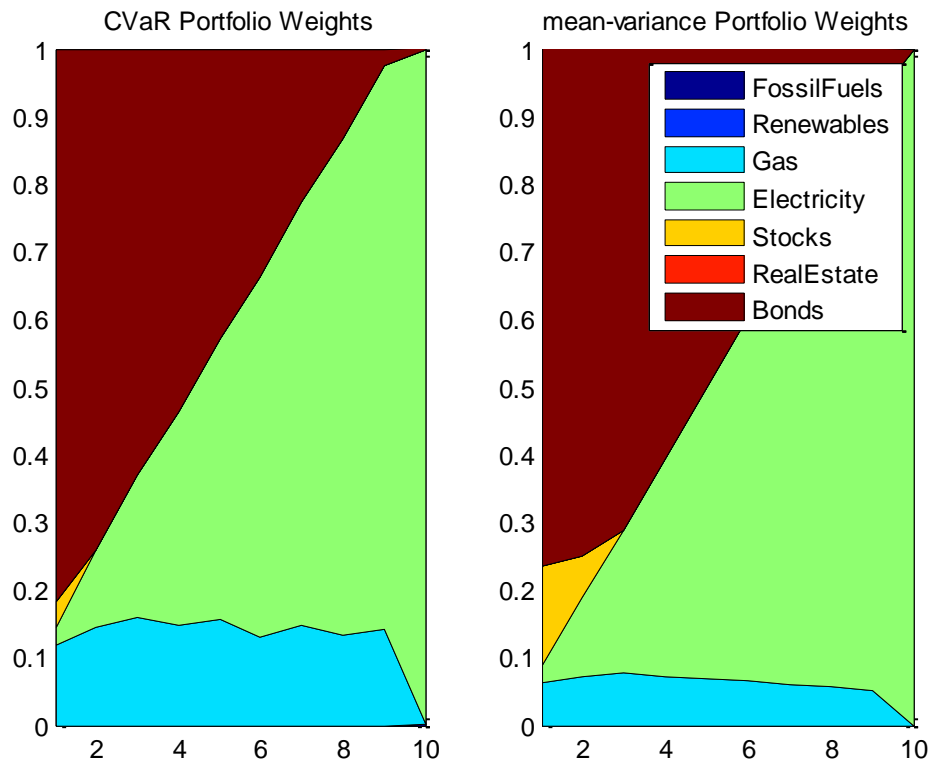
664 When comparing the weights of the two optimizations, we observe that using the M-
665 CVaR optimization invests in the same assets as the Mean-Variance optimization,
666 which are: Government Bonds, Gas, Electricity and Stocks. The allocation in certain
667 assets differs as can be seen from Figure 6. In the M-CVaR optimization more is
668 invested in Gas and less in Stocks than the Mean-Variance portfolio weights. The
669 Appendix depicts the differences present in the first portfolios of the efficient frontier
670 and this explains the differences of the frontiers in the lower level of return/risk ratio.
671 However, since our results are analytically significant we can confirm our conclusion
672 that an investor can still benefit even if he/she focuses on a single infrastructure sector.

673

674 **Figure 6.** Weight Comparison for Portfolios Mean-Variance and M-CVaR

675 optimization

676



677

678 - **Portfolio 4 specialises only in transport sub-sector assets (Airports, Ports and**
679 **Toll Roads) within a traditional portfolio (e.g., Stocks, Real Estate and**
680 **Government Bonds)**

681 In the last considered portfolio, we evaluate the diversification benefits gained by
682 investing only in the Transport sector. For this reason we construct a portfolio that
683 includes only Transport sub-sector assets within a traditional portfolio.

684

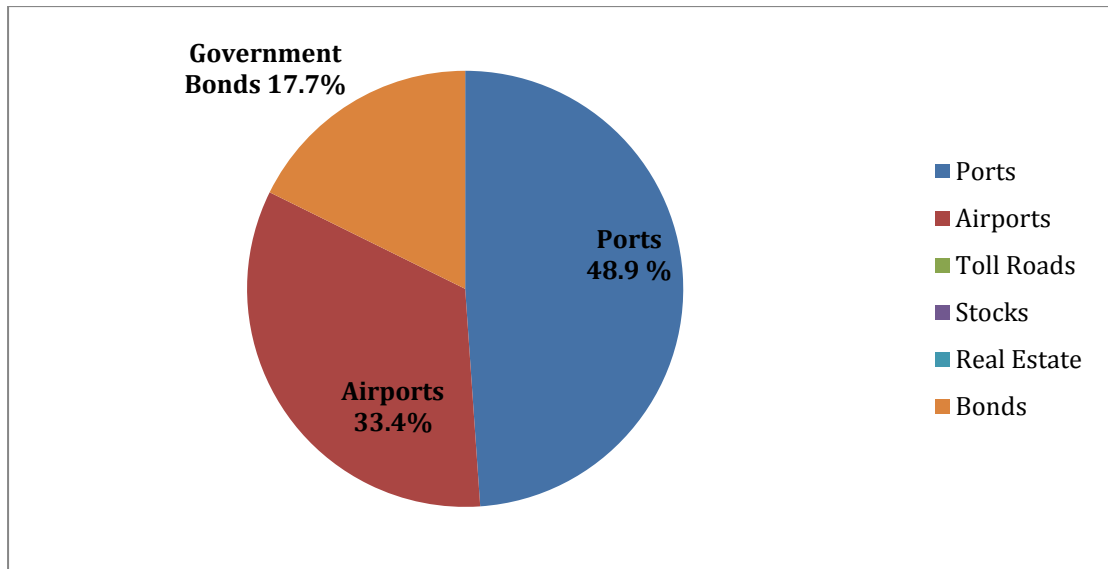
685 When building a multi-asset portfolio which includes Transport sub-sectors, Stocks,
686 Real Estate and Government Bonds, the maximum Sharp Index achieved is 0.428 and

687 the portfolio invests 48.9% in Ports, 33.4% in Airports, and 17.7% in Government
688 Bonds.

689

690 **Figure 7.** Optimal Portfolio in the Optimisation of the Transport sector

691



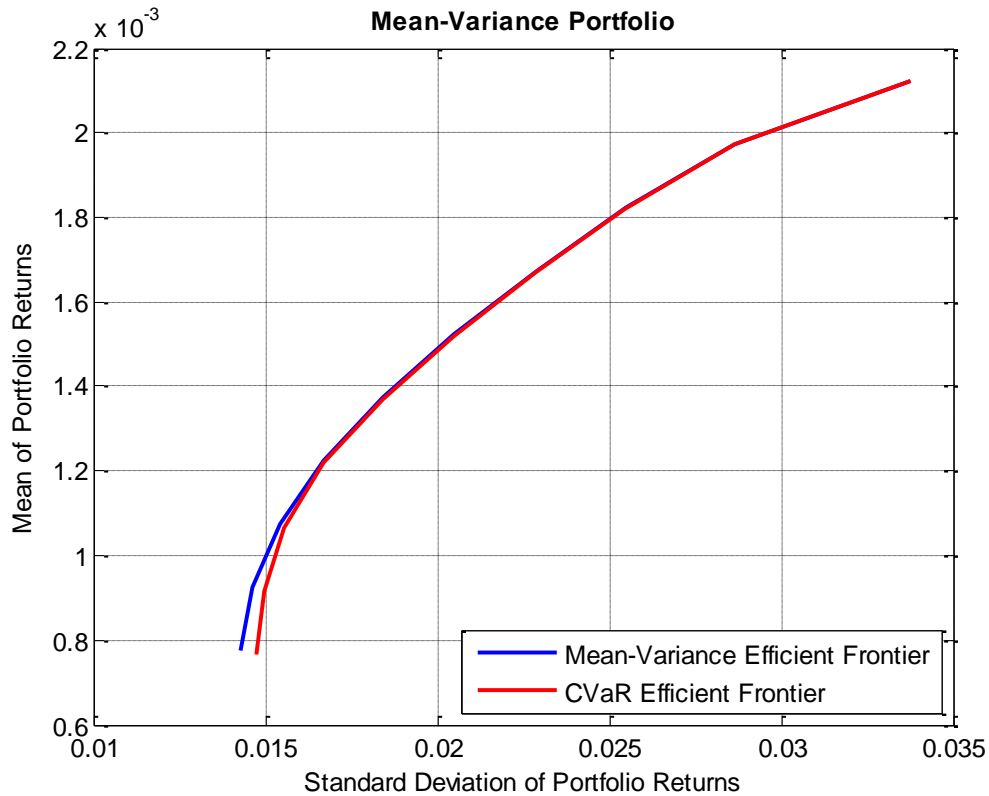
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693

694 Similar to the two previous optimizations, the results are robust when undertaking the
695 M-CVaR optimization. When comparing the two efficient frontiers (Figure 8), we can
696 observe that the frontiers are very similar apart from the small differences observed at
697 the lower levels.

698

699 **Figure 8.** Efficient frontiers for Portfolios Mean-Variance and M-CVaR optimization



700

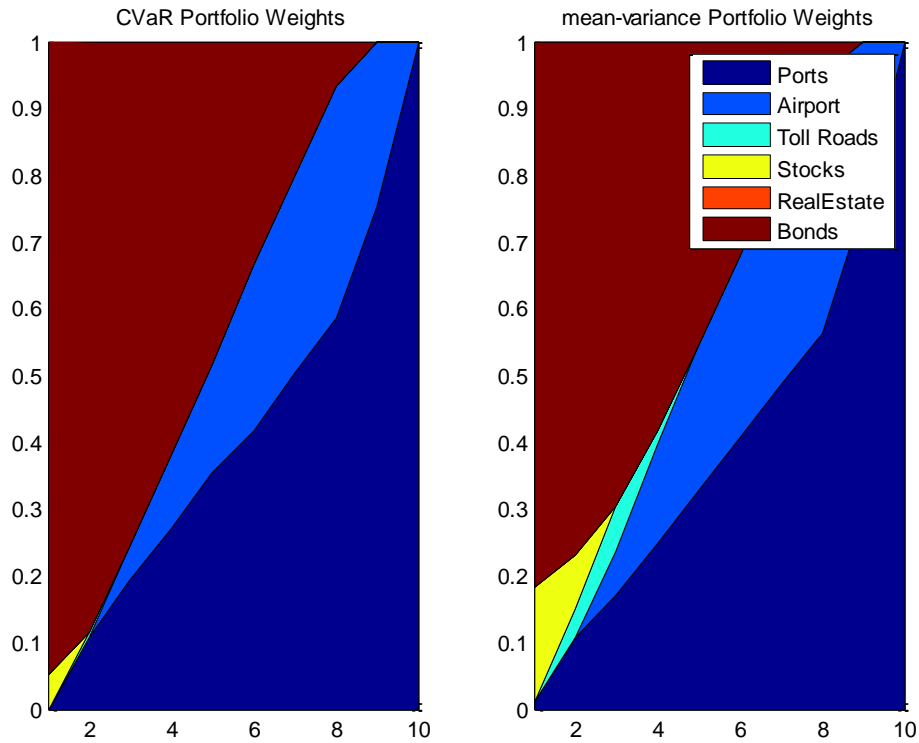
701

702 When comparing then the allocation of the assets in the two optimizations we observe
 703 from Figure 9, that in the Mean-Variance portfolio weights more is invested in Toll
 704 Roads and in Stocks relatively, to the CVaR Portfolio Weights. As can be seen from
 705 the efficient frontiers portfolios in the Appendix, the differences in the allocation of
 706 certain assets lie in the portfolios at the lower level of the risk/return ratio. However,
 707 given the similarity of the results we certainly conclude that investor should only focus
 708 and invest in a single sector.

709

710 **Figure 9.** Efficient frontiers for Portfolios Mean-Variance and M-CVaR optimization

711



712

713

714 **6. Conclusions**

715 The importance of infrastructure to the economic welfare of countries is well-
 716 recognised among economists, governments and policy makers. The provision of good
 717 quality infrastructure is on the agenda of every European government, as infrastructure
 718 is the path to increased living standards, economic growth and a means of escaping the
 719 recession from which many European governments still suffer. However, the
 720 importance of infrastructure investment not only rests with governments that turn to
 721 infrastructure as a way to boost their economies. Institutional investors are also paying
 722 close attention to infrastructure assets, particularly the European assets. According to
 723 Prequin (2013), from the 3700 infrastructure deals that took place since 2008, an annual
 724 average of 47% are deals made in European assets.

725

726 Despite greater focus and attention being given to European infrastructure assets, little
727 research to date has examined the performance and portfolio implications of this asset
728 class. The economic importance and investment characteristics of infrastructure have
729 been studied mainly at the global level since the late 1980s, with minimal study of
730 different infrastructure sectors (Finkenzeller et al. 2010). As Oyedele (2013, p. 3) has
731 asserted, “infrastructure is an incorporation of many heterogeneous sectors including
732 roads, bridges, ports, power generation, electricity, gas utilities and
733 telecommunications with no two having identical attributes.”

734

735 Due to the importance of European infrastructure assets in the global context, and the
736 existence of heterogeneity among different infrastructure sectors and sub-sectors, we
737 have in this paper evaluated the performance of different listed European economic
738 infrastructure assets, i.e., Energy, Utilities, Telecommunications, and Transport over a
739 period that also captures the effects of the financial crisis. The present paper has also
740 provided a performance analysis of Energy and Transport sub-sector indices as a way
741 to more closely scrutinise the behaviour differences and similarities of a selection of
742 sub-sectors. The paper has also examined the significance of including infrastructure in
743 a mixed asset portfolio and has attempted to determine the best way to construct and
744 invest in an infrastructure portfolio.

745

746 The results of the European analysis indicate that infrastructure sectors and sub-sectors
747 perform differently and show variations in annual returns and volatilities. In response,
748 greater attention should be paid to specific infrastructure sectors. Not only is knowledge
749 about the performance of different infrastructure sectors crucially important to fund
750 managers, but so is knowledge about each sub-sector equally vital.

751 Our findings in the second part of the analysis conclude that when the infrastructure
752 sector is combined with other traditional assets, the portfolio yields a higher Sharp Index
753 than the Sharp Index that would be gained by investing in any single asset. Nonetheless,
754 the evidence presented in this study leads to our rejection of the proposition that listed
755 infrastructure can be treated as a separate asset class. We have determined that investing
756 in listed infrastructure is beneficial as long as it is a subset of a traditional portfolio.
757 Furthermore, according to the present research, the creation of a portfolio that invests in
758 a variety of infrastructure sectors is never an optimal solution. For this reason, we have
759 performed a sub-sector Transport and Energy portfolio analysis, and through this
760 analysis we can confirm that there are indeed diversification benefits, even within a
761 specific infrastructure sector.

762

763 The recent financial crisis has imposed strict constraints on the availability of public
764 funds, such that limited available resources must be spent as efficiently as possible;
765 governments are thereby required to select and prioritise among various infrastructure
766 projects (Szimba and Rothengatter 2012). This research has shown that, by focussing
767 on one listed infrastructure sector, a fund manager can gain complete knowledge of the
768 performance of the sector and still enjoy diversification benefits. An exciting
769 implication of this finding is that if a country lacks investment in one particular sector,
770 it can invest in this sector and still be able to diversify its infrastructure investment
771 portfolio.

772

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Appendix

873 Efficient frontier sets for all the portfolios

874 - **Portfolio 1 includes only European traditional assets using Mean-Variance**
875 **Optimisation**

Portfolio Volatility	Stock	Govt. Bonds	Real Estate	Portfolio Return	Sharp Index
9.76%	18.8%	81.2%	0%	4.91%	0.358
10.1%	6.23%	93.8%	0%	5.27%	0.384
10.3%	0%	100%	0%	5.46%	0.392
11.8%	0%	83.2%	16.8%	5.64%	0.360
13.8%	0%	66.5%	33.5%	5.83%	0.321
16.2%	0%	49.9%	50.1%	6.01%	0.285
18.8%	0%	33.3%	66.7%	6.19%	0.254
21.7%	0%	16.6%	83.4%	6.38%	0.229
24.5%	0%	0%	100%	6.56%	0.210

876

877 - **Portfolio 2 includes the same assets as portfolio 1, plus the addition of all**

878 **infrastructure sectors using Mean-Variance Optimisation**

Portfolio Volatility	Energy	Telecom	Utilities	Transport	Stocks	Real Estate	Govt. Bonds	Portfolio Return	Sharp Index
9.76%	0%	0%	0%	0%	18.8%	0%	81.2%	4.91%	0.358
10.3%	0%	0%	0%	1.54%	3.92%	0%	94.5%	5.40%	0.389
11.2%	0%	0%	0%	11.3%	0%	0%	88.7%	5.90%	0.400
12.1%	0%	0%	0%	21.4%	0%	0%	78.6%	6.29%	0.402
14.1%	0%	0%	0%	36.6%	0%	0%	63.4%	6.88%	0.389
15.8%	0%	0%	0%	49.3%	0%	0%	50.7%	7.38%	0.377
17.7%	0%	0%	0%	62.0%	0%	0%	38.0%	7.87%	0.364
19.8%	0%	0%	0%	74.7%	0%	0%	25.3%	8.36%	0.352
21.8%	0%	0%	0%	87.3%	0%	0%	12.7%	8.86%	0.341
23.8%	0%	0%	0%	100%	0%	0%	0%	9.35%	0.334

879

880 - **Portfolio 2 includes the same assets as portfolio 1, plus the addition of all**

881 **infrastructure sectors using Mean Conditional Value-at-Risk**

882 **Optimisation**

Portfolio	Conditional VaR	Energy	Telecom	Utilities	Transport	Stocks	Real Estate	Bonds	Portfolio Return
10.0%	0.070	0%	0%	0%	0.0%	7.40%	0%	92.6%	5.24%
10.8%	0.075	0%	0%	0%	6.20%	0%	0%	93.8%	5.70%
11.9%	0.084	0%	0%	0%	17.9%	0%	0%	82.1%	6.15%
13.2%	0.094	0%	0%	0%	29.7%	0%	0%	70.3%	6.61%
14.7%	0.105	0%	0%	0%	41.4%	0%	0%	58.6%	7.07%
16.4%	0.118	0%	0%	0%	53.1%	0%	0%	46.9%	7.52%
18.2%	0.132	0%	0%	0%	64.8%	0%	0%	35.2%	7.98%

20.1%	0.146	0%	0%	0%	76.6%	0%	0%	23.4%	8.44%
22.0%	0.159	0%	0%	0%	88.3%	0%	0%	11.7%	8.90%
23.8%	0.173	0%	0%	0%	100%	0%	0%	0.0%	9.35%

883

884 - **Portfolio 3 specialises only in the energy sub-sector assets (Natural Gas,**
885 **Electricity, Fossil fuels, Renewable Energy) within a traditional portfolio**
886 **using the Mean-Variance Optimisation**

Portfolio Volatility	Fossil Fuels	Renewable Energy	Natural Gas	Electricity	Stocks	Real Estate	Govt. Bonds	Portfolio Return	Sharp Index
10.0%	0%	0%	6.36%	2.49%	14.6%	0%	76.6%	4.16%	0.249
10.1%	0%	0%	7.18%	11.6%	6.31%	0%	74.9%	4.44%	0.276
10.3%	0%	0%	7.70%	21.2%	0%	0%	71.1%	4.73%	0.299
10.8%	0%	0%	7.29%	32.1%	0%	0%	60.6%	5.02%	0.311
11.7%	0%	0%	6.87%	43.1%	0%	0%	50.0%	5.30%	0.311
13.0%	0%	0%	6.46%	54.0%	0%	0%	39.5%	5.59%	0.303
14.4%	0%	0%	6.05%	65.0%	0%	0%	29.0%	5.87%	0.292
16.1%	0%	0%	5.63%	76.0%	0%	0%	18.4%	6.16%	0.280
17.8%	0%	0%	5.22%	86.9%	0%	0%	7.87%	6.44%	0.268
19.7%	0%	0%	0%	100%	0%	0%	0%	6.74%	0.258

887

888 - **Portfolio 3 specialises only in the energy sub-sector assets (Natural Gas,**
889 **Electricity, Fossil fuels, Renewable Energy) within a traditional portfolio**
890 **using the Mean- Conditional Value-at-Risk Optimisation**

891

Volatility	C-VaR	Fossil Fuels	Renewable Energy	Natural Gas	Electricity	Stocks	Real Estate	Government Bonds	Return
10.2%	0.033	0%	0%	11.8%	2.83%	3.81%	0%	81.6%	4.28%
10.2%	0.033	0%	0%	14.5%	11.3%	0%	0%	74.2%	4.55%
10.5%	0.035	0%	0%	15.9%	21.0%	0%	0%	63.1%	4.82%
11.1%	0.037	0%	0%	14.6%	31.8%	0%	0%	53.6%	5.09%
12.1%	0.041	0%	0%	15.5%	41.7%	0%	0%	42.8%	5.37%
13.3%	0.045	0%	0%	13.1%	53.1%	0%	0%	33.9%	5.64%
14.7%	0.050	0%	0%	14.8%	62.6%	0%	0%	22.6%	5.91%
16.3%	0.056	0%	0%	13.3%	73.5%	0%	0%	13.2%	6.18%
18.0%	0.061	0%	0%	14.3%	83.4%	0%	0%	2.35%	6.46%
19.7%	0.068	0%	0%	0%	100%	0%	0%	0%	6.74%

892 - Portfolio 4 includes Transport sub-sector assets (Airports, Ports, and Toll
893 Roads) within a traditional portfolio using Mean-Variance Optimisation

894

Portfolio Volatility	Ports	Airports	Toll Roads	Stocks	Real Estate	Bonds	Portfolio Return	Sharp Index
10.3%	1.17%	0%	0%	17.2%	0%	81.6%	4.03%	0.230
10.5%	10.7%	0%	4.22%	8.19%	0%	76.9%	4.80%	0.299
11.1%	17.0%	6.65%	6.75%	0%	0%	69.6%	5.58%	0.353
12.0%	24.8%	14.9%	1.84%	0%	0%	58.4%	6.36%	0.391
13.3%	32.7%	21.6%	0%	0%	0%	45.7%	7.14%	0.413
14.8%	40.6%	27.3%	0%	0%	0%	32.1%	7.92%	0.424
16.6%	48.9%	33.4%	0%	0%	0%	17.7%	8.76%	0.428
18.3%	56.4%	38.8%	0%	0%	0%	4.81%	9.48%	0.426
20.7%	75.2%	24.8%	0%	0%	0%	0%	10.3%	0.416
24.3%	100%	0%	0%	0%	0%	0%	11.1%	0.386

895

896 - Portfolio 4 includes Transport sub-sector assets (Airports, Ports, and Toll
897 Roads) within a traditional portfolio using Mean- Conditional Value at Risk

898 Optimisation

899

Portfolio Volatility	C-VaR	Ports	Airports	Toll Roads	Stocks	Real Estate	Bonds	Portfolio Return
10.6%	0.034	0%	0%	0%	5.1%	0%	94.9%	3.98%
10.8%	0.035	10.7%	0%	0.8%	0%	0%	88.5%	4.77%
11.2%	0.038	19.3%	4.98%	0%	0%	0%	75.7%	5.55%
12.0%	0.041	27.1%	11.0%	0%	0%	0%	61.9%	6.33%
13.3%	0.045	35.3%	16.3%	0%	0%	0%	48.4%	7.12%
14.7%	0.051	41.7%	24.8%	0%	0%	0%	33.5%	7.90%
16.5%	0.057	50.3%	29.4%	0%	0%	0%	20.3%	8.68%
18.3%	0.064	58.5%	34.8%	0%	0%	0%	6.7%	9.47%
20.6%	0.071	75.1%	24.9%	0%	0%	0%	0%	10.3%
24.3%	0.084	100%	0%	0%	0%	0%	0%	11.1%

900