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Jakob Thomä

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OPTIMAL DIVERSIFICATION AND THE TRANSITION TO NET ZERO: A METHODOLOGICAL FRAMEWORK FOR MEASURING CLIMATE GOAL ALIGNMENT OF INVESTOR PORTFOLIOS

THÈSE dirigée par :

Madame KARYOTIS, Catherine	Chercheur associée au LIRSA, CNAM

RAPPORTEURS :

Madame LOUCHE, Celine	Professeure, Audencia Business School
Madame CRIFO, Patricia	Professeure, Université Paris Nanterre

---

JURY :

Monsieur CHENET, Hugues	Administrateur, 2° Investing Initiative
Monsieur POIVET, Romain	Chargé de projet climat, ADEME
Madame RÖTTMER, Nicole	PDG, The CO-Firm
Monsieur PESQUEUX, Yvon	Professeur titulaire de la Chaire "Développement des Systèmes d'Organisation", établissement, CNAM
Madame LOUCHE, Celine	Professeure, Audencia Business School
Madame CRIFO, Patricia	Professeure, Université Paris Nanterre

Dedicated to those serving the public good
and their loved ones

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Résumé en français

La thèse vise à développer un cadre pour mesurer l'alignement des portefeuilles financiers avec les objectifs climatiques, prenant comme point de départ à la fois la théorie traditionnelle du portefeuille moderne et les cadres d'analyse des risques financiers, ainsi que la science du climat. Il s'agit de la première tentative d'élaboration de points de repère scientifiques pour le portefeuille financier.

Le cadre utilise comme point de départ le concept de «diversification optimale» basé sur la théorie moderne du portefeuille et l'hypothèse de marché efficace. Selon cette théorie, les stratégies optimales impliquent l'achat du «portefeuille de marché». Il postule que cette stratégie ne peut toutefois pas être alignée sur une stratégie de portefeuille alignée avec un scenario 2 ° C. Une telle stratégie de portefeuille basée sur la science peut toutefois avoir un sens pour les institutions financières qui considèrent des objectifs multiples (financiers et non financiers) ou des institutions financières qui pensent que les marchés évaluent mal les risques financiers associés à la transition vers une économie 2°C. Les stratégies associées à 2°C peuvent surperformer le marché. Sous l'hypothèse que la transition vers une économie bas-carbone présente un facteur de risque, pour lequel la thèse fournit une série de preuves théoriques, les stratégies de portefeuille peuvent chercher à acheter le «marché à 2 ° C» en cherchant et gérant une «diversification optimale». Le modèle étend ainsi la logique de la diversification pour réduire le risque, inhérent à la théorie moderne du portefeuille, de la classe d'actifs au niveau sectoriel et technologique. Après le développement du modèle, le modèle a été testé par une série de compagnies d'assurance, de gestionnaires d'actifs et de gestionnaires de portefeuille. Au total, plus de 250 investisseurs institutionnels ont appliqué le modèle au moment de la publication. En outre, le modèle a été testé sur environ 10000 fonds. De plus, deux banques centrales européennes ont appliqué le modèle en interne dans le cadre d'une analyse de scénario à 2 ° C de leurs entités réglementées (fonds de pension et compagnies d'assurance). Dans le cadre d'un sondage auprès de 25 investisseurs, 88% ont déclaré que le cadre était tout aussi pertinent ou plus pertinent que les évaluations climatiques existantes, et 88% ont indiqué qu'ils étaient susceptibles ou très susceptibles d'utiliser la méthodologie pour aller de l'avant.

Mots clés :

Changement climatique ; Théorie modern du portefeuille ; Finance

Résumé en anglais

The thesis seeks to develop a framework to measure the alignment of financial portfolios with climate goals, taking as point of departure both traditional modern portfolio theory and financial risk analysis frameworks, as well as climate science. It represents the first attempt to develop science-based benchmarks for financial portfolios.

The framework uses as the starting point the concept of 'optimal diversification' based on the modern portfolio theory and efficient market hypothesis. Under this theory, optimal strategies involve buying the 'market portfolio'. It posits that a 2°C aligned, science-based portfolio strategy is not aligned with such a strategy. Such a science-based portfolio strategy, in turn, may make sense for financial institutions that consider multiple objectives (e.g. financial and non-financial) or financial institutions that think markets are mispricing financial risks associated with the transition to a low-carbon economy and that associated low-carbon, or 2°C aligned strategies can outperform the market. Under the assumption that the transition to a low-carbon economy presents a risk factor, for which the thesis provides a range of theoretical evidence, portfolio strategies can seek to buy the '2°C market' by managing 'optimal diversification' to the 2°C aligned technology set, in addition to managing sector exposures. The model thus extends the logic of diversification to reduce risk, intrinsic to the modern portfolio theory, from asset class to sector and technology level.

Following the development of the model, a range of insurance companies, asset managers, and portfolio managers tested the model. In total, over 250 institutional investors have applied the model to date. In addition, the model has been tested on around 10,000 funds. Moreover, two European central banks have applied the model internally as part of 2°C scenario analysis of their regulated entities (pension funds and insurance companies). As part of a feedback survey with 25 investors, 88% said the framework was equally or more relevant than existing climate assessments, and 88% said they were likely or very likely to use the methodology moving forward.

Keywords:

Climate Change; Modern Portfolio Theory; Finance

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DIVERSIFICATION OPTIMALE ET LA TRANSITION AU ZÉRO NET: UN CADRE MÉTHODOLOGIQUE POUR MESURER L'ALIGNEMENT DES PORTEFEUILLES DES INVESTISSEURS AVEC LES OBJECTIFS CLIMATIQUES

Introduction

Les marchés financiers sont un des éléments constitutifs de toute économie. En fixant le prix des actifs et en allouant les ressources à destination des investissements réalisés par les entreprises, les ménages et les gouvernements, ils sont essentiels au bon fonctionnement des économies et sources d'information en termes d'orientation macroéconomique.

Leur importance fait donc d'eux une pierre angulaire essentielle pour financer l'économie mondiale. Aujourd'hui, l'un des défis majeurs pour la génération actuelle consiste en ce que ces marchés financiers veillent à limiter le réchauffement de la planète bien en deçà de 2°C. En effet, le réchauffement climatique représente une menace fondamentale pour notre économie, notre santé, notre ordre politique et social et la stabilité de la planète. Sa limitation est la condition sine qua non de survie des populations et les marchés financiers doivent obligatoirement y répondent de manière appropriée ; ils doivent contribuent à atteindre l'objectif de limitation du réchauffement climatique - spécifiquement et idéalement dans une mesure compatible avec le changement climatique bien inférieur à 2° C au-dessus des niveaux préindustriels. C'est l'objectif défini dans l'Accord de Paris, l'accord international sur le climat définissant le mandat politique.

Cette thèse vise à développer un cadre permettant de mesurer si les marchés financiers allouent effectivement des capitaux de manière cohérente à cet objectif. Ce faisant, elle cherche à reformuler ou peut-être plus précisément à élargir le cadre qui régit actuellement les décisions d'investissement sur les marchés financiers, basé sur la théorie moderne du portefeuille. Le travail consiste à rechercher un alignement des marchés financiers avec ces objectifs climatiques non comme un objectif auxiliaire, mais un objectif fondamental de la théorie des portefeuille en se focalisant sur le concept de diversification optimale.

La thèse fait valoir deux points clés. La première est qu'une diversification optimale pour une institution financière ne peut pas être simplement décrite en termes de répartition des actifs dans un portefeuille cohérent *avec les prix de ces actifs* mais aussi avec l'activité économique dans laquelle ces actifs sont engagés. Le deuxième point est une diversification optimale. On ne décrit pas uniquement en termes d'*optimisation financière*, mais aussi en réponse à d'autres objectifs - notamment dans ce cas-ci celui de l'allocation du capital d'une manière cohérente avec les objectifs climatiques.

Sur la base de ces deux points, la thèse s'appuie sur la théorie traditionnelle du portefeuille moderne pour développer une nouvelle façon de penser la diversification optimale, au-delà des préoccupations financières et climatiques et au-delà des prix des actifs et des considérations économiques. La majeure partie de la littérature académique au cours du dernier demi-siècle a cherché soit à abandonner la théorie moderne du portefeuille, soit à la modifier, en plaidant pour la présence d'exceptions ou de facteurs bêta. Cette thèse n'essaie pas d'y parvenir. Elle réaffirme la théorie moderne du portefeuille à la lumière de la diversification économique optimale et des objectifs alternatifs.

Le travail doctoral développe la manière dont ce cadrage peut s'asseoir sur la théorie traditionnelle du portefeuille moderne (chapitre 1) et pourquoi la théorie traditionnelle peut ne pas saisir ce nouvel objectif (chapitre 2). Il met en évidence le lien entre les marchés financiers et les objectifs climatiques (chapitre 3) et les principes comptables clés qui peuvent régir cette relation (chapitre 4). La thèse introduit ensuite un cadre alternatif, s'appuyant sur les principes clés de la théorie moderne du portefeuille (chapitre 5) et montre comment cela peut être appliqué dans la pratique (chapitre 6), ainsi que les défis et insuffisances qui existent encore (chapitre 7). La thèse se termine par une discussion de l'impact potentiel des décisions sur les marchés financiers sur la base du nouveau cadre (chapitre 8) et des implications réglementaires et politiques (chapitre 9). La conclusion discute de l'endroit où, après avoir réinitialisé les signaux, l'avenir peut s’entreprendre.

Le modèle décrit ici a été testé par plus de 250 institutions financières à ce jour, trois autorités de surveillance financière et un gouvernement. On estime que 10 billions d'euros d'actifs sous gestion ont été testés à ce jour en utilisant le modèle. Il s'appuie sur des données couvrant environ 90% des centrales électriques, des champs pétroliers et gaziers, des mines de charbon, des cimenteries, des aciéries, des navires, des avions et des usines automobiles appartenant à des entreprises. La recherche ne fournit pas seulement un modèle, mais plutôt un cadre comptable général qui accueille différentes questions de recherche sur mesure, les approches, les concepts et les croyances d'investissement. En cela, la question de recherche posée - l'alignement des portefeuilles financiers et la diversification optimale compatible avec une transition nette à zéro - montre en réalité toute une gamme de questions de recherche nécessitant des approches différentes.

La théorie modern du portefeuille et le lien avec climat

Dans son travail « Sélection de portefeuille: diversification efficace des placements », Markowitz (1952) développe une relation mathématique entre le risque et le rendement, montrant que le rendement attendu d'un portefeuille est la moyenne pondérée du rendement attendu de chaque titre. Le risque de volatilité (écart type) est inférieur à sa moyenne pondérée si la corrélation entre les titres est inférieure à la valeur absolue. Markowitz poursuit en soutenant que ce portefeuille qui optimise le rendement tout en minimisant les risques repose sur la frontière efficiente.

S'inspirant de cette théorie, Tobin (1958) s'est appuyé sur le travail de Markowitz en inventant le concept de « portefeuille super efficient » - le portefeuille que tout investisseur devrait détenir en combinaison avec un actif sans « risque » (par exemple, espèces). Le rapport entre le portefeuille sans risque et le portefeuille super efficient serait alors déterminé par l'aversion au risque de l'investisseur. Sa théorie est également connue sous le nom de « théorème de séparation ». Tobin a donc fait le saut intellectuel de l'investissement à la théorie du portefeuille à l'aube de l'allocation d'actifs moderne, la source de richesse pour les consultants en investissement à travers le monde.

La combinaison de l'hypothèse de marché efficient et de la vision de la théorie moderne du portefeuille de Markowitz a conduit au modèle d'évaluation des actifs de Sharpe (1964), selon lequel le portefeuille super efficient de Tobin était en réalité le *portefeuille* du marché. Dans le modèle CAPM, Sharpe suggère qu'il existe deux types de risques: le risque systémique, à savoir le risque de marché (appelé bêta), qui est contenu dans tous les titres, et le risque idiosyncratique (alpha), à savoir le risque individuel pour un niveau de sécurité donné. En d'autres termes, lorsque les prix d'un titre individuel augmentent à mesure que les prix du marché baissent, c'est la manifestation de l'alpha. Lorsqu'un investisseur achète le portefeuille de marché super efficient, il élimine tout risque idiosyncratique.

Le modèle CAPM reste le support théorique le plus dominant dans la gestion de portefeuille à ce jour. Ajusté, abrégé, mais jamais abandonné, il continue d'orienter les décisions d'investissement des institutionnels du monde entier. Cependant, il a été contesté et développé. La plupart des ajustements et des développements ultérieurs de CAPM supposent un certain type de « facteur » qui permet une surperformance au-delà du simple achat du marché. Ainsi, Black et al. (1972) montrent que « les portefeuilles construits pour n'avoir aucune covariance avec le marché ont des rendements moyens qui dépassent largement le taux sans risque, ce qui suggère qu'il existe (au moins) un autre facteur que le marché qui affecte systématiquement le rendement des titres ».

Les académiques ont mené des travaux de recherche en définissant exactement quels étaient ces facteurs, en cherchant sous une forme ou une autre à faire de l'argent à partir de risques ou de rendements qui ne sont pas correctement évalués par le marché. Ce développement ultérieur est par exemple repris dans la Théorie de l'Arbitrage Pricing développée par Ross (1976), qui soutient qu'il existe de nombreux bêtas sans limite de facteurs et que ceux-ci restent indéfinis en théorie. L'arbitrage consiste à sélectionner des actifs « mal évalués » pour obtenir des rendements supérieurs à ceux du marché pour ceux qui identifient cette tarification erronée.

Le facteur 'transition énergétique'

Ainsi, à la lecture de ces théories, les investisseurs achètent le marché, à des degrés divers de « précision », le marché est efficient ; dès lors pourquoi s'inquiéter de l'alignement des portefeuilles avec les objectifs climatiques. Il y a deux aspects ici. L'un s'appuie sur les modèles factoriels, suggérant que les risques financiers associés à la transition vers une économie à bas carbone pourraient ne pas être correctement évalués par les marchés financiers. L'alignement des portefeuilles financiers sur les objectifs climatiques peut ainsi assurer une surperformance par rapport au marché si et quand cette transition se matérialise. Ce que cette thèse explore est la mesure dans laquelle cela peut être conceptualisé comme une réaffirmation plus large de la diversification optimale du point de vue de l'activité économique, plutôt que comme une « inclinaison » visant à capturer un bêta. La tarification erronée peut également présenter un intérêt pour les autorités de surveillance financière qui cherchent à surveiller les bulles de prix des actifs sur les marchés financiers. L'autre aspect réside dans l'angle de politique publique où les marchés évaluent correctement les risques de transition, les modèles de mesure de l'alignement avec les objectifs climatiques éclairent donc les décideurs politiques sur l'adéquation des signaux de la politique climatique aux risques et aux rendements des marchés financiers. Chacun de ces éléments est discuté dans le chapitre suivant.

L'angle de la politique climatique est clair. Il consiste en l'idée que les marchés sont efficients, et les décisions d'allocation du capital de marché éclairent donc les décideurs sur la suffisance des politiques climatiques. À cette fin, il est impératif que les décideurs aient une visibilité sur l'alignement des marchés financiers sur les objectifs climatiques, non pas parce qu'un désalignement serait ou devrait être interprété comme une mauvaise évaluation du risque, mais parce qu'il montre que les politiques climatiques sont trop faibles. De facto, il convient de savoir, tout particulièrement pour les institutions financières, de savoir s'il existe réellement une mauvaise évaluation.

La première étape pour répondre à cette question est de comprendre comment la transition vers une économie bas carbone est source de risques financiers. Au cours des dernières années, les risques financiers associés à la transition vers une économie bas carbone, axée sur l'avenir des combustibles fossiles et du secteur de l'énergie, ont été de plus en plus nombreux (Meinshausen 2009, Robins 2012, Leaton 2013, Caldecott 2015). Cet ensemble de recherches soutient que la transition vers une économie bas carbone mène à la création et à la destruction de valeur susceptibles d'avoir une incidence sur la viabilité financière des actifs dans les bilans des entreprises et des gouvernements et l'évaluation des actifs financiers (par exemple actions et obligations). Ces risques sont généralement qualifiés de « risques de transition ».

Les risques de transition peuvent être importants dans l'ensemble de la chaîne d'investissement et dans l'ensemble de l'économie. Ces risques peuvent apparaître à chaque étape de la chaîne en fonction des politiques, des changements du marché, des défis juridiques et des impacts sociaux / réputationnels. En effet, les risques peuvent être « transmis » à travers la chaîne, des actifs physiques aux entreprises, aux institutions financières, aux gouvernements et à la société civile:

- Les actifs physiques sont fréquemment les premiers à l'origine de risques de transition, de par leur exposition aux contraintes politiques, juridiques, de marché et de réputation. En Europe, ces risques ont sans doute déjà commencé à se matérialiser.

- Les entreprises peuvent être soumises à des risques de transition à la fois par la dépréciation d'actifs physiques et par des contraintes directes imposées aux entreprises par des mesures réglementaires, juridiques ou de réputation. Les institutions financières sont exposées à ces risques via leurs actions cotées, ainsi que via leurs portefeuilles d'obligations et leurs activités de prêts.

- Les institutions financières sont exposées aux risques de leurs entités émettrices (entreprises, ménages, gouvernements). En outre, elles pourraient également être confrontées à des contraintes réglementaires auxquelles elles sont soumises. Le risque de transition pourrait être pris en compte pour établir des notations de crédit, des évaluations d'entreprises et des modèles de risque de marché. Si à ce stade, une grande partie de l'attention a été portée sur les entreprises, des risques peuvent également apparaître pour les actifs financiers « non corporate », notamment la dette souveraine et celle des ménages.

- Les gouvernements et la société civile sont exposés aux risques de transition, directement ou indirectement, par le biais de la chaîne d'investissement, jusqu'au propriétaire ultime des actifs et, dans certains cas, au gouvernement.

À ce jour, la recherche sur ces risques s'est principalement concentrée sur l'examen de leur importance potentielle pour les actifs et les acteurs des marchés financiers. Parmi les exemples notables, citons la recherche sur le risque de transition aux actifs physiques (Caldecott 2016, Fulton 2016, Ekins 2015), les actifs financiers (Robins 2012) et les portefeuilles financiers (Mercer 2015). Moins exploré dans ce débat est la question de savoir si les acteurs des marchés financiers ont déjà correctement tarifé ces risques, remettant en cause l'hypothèse de « bulle ».

Ainsi, il y a un consensus de plus en plus fort selon lequel ces risques peuvent se matérialiser, sans savoir pour autant pas s'ils sont en compte dans les prix des actifs actuels. C'est notamment le cas des entreprises de combustibles fossiles qui ont perdu dans certains cas plus de 50% de leur capitalisation boursière au cours de cette décade ou encore des sociétés charbonnières qui ont connu des faillites croissantes aux États-Unis. De même, les services publics européens à forte émission de carbone ont également souffert. Bien qu'il existe des preuves académiques d'un point de bascule soudain dans les politiques climatiques qui peuvent créer des risques de transition soudains et inattendus (Aghion 2014), une telle littérature ne remet pas directement en question les probabilités de telles surprises.

La question de la mauvaise évaluation des actifs est essentielle pour deux raisons. Premièrement, une bonne évaluation est importante du point de vue de la stabilité financière, car une mauvaise tarification des actifs peut entraîner des bulles d'actifs qui peuvent avoir des effets systémiques ou, à tout le moins, créer des risques financiers pour certains acteurs et classes d'actifs. Deuxièmement, et lié au premier, la mauvaise évaluation des actifs est également pertinente d'un point de vue politique et social. La mauvaise évaluation des actifs peut conduire à une allocation de capital inefficace, qui à son tour peut inhiber la croissance, car le capital n'est pas utilisé au mieux.

Dans le cas particulier du carbone, cela peut être encore plus problématique dans la mesure où une allocation du capital inefficace peut exacerber les inefficiences économiques liées à la mauvaise évaluation du coût social du carbone. Ainsi, la tarification non seulement inhibe la croissance, mais elle a aussi un impact négatif supplémentaire sur le bien-être public en général, à travers des impacts négatifs sur la santé (Watts et al., 2015) et d'autres coûts sociaux et politiques.

Pour comprendre pourquoi les risques de transition énergétique en tant que classe de risque particulière peuvent être mal évalués, il est important d'examiner d'abord la littérature théorique sur les défaillances du marché, notamment les principes mis en évidence ci-dessus: notamment la théorie du choix rationnel et les hypothèses de distribution normales.

L'une des critiques théoriques les plus fortes du modèle de maximisation de l'utilité vient de Herbert Simon (1957), qui a inventé le terme de « rationalité bornée » : L'auteur soutient, et il convient de le citer longuement, que « la capacité de l'esprit humain à formuler et à résoudre des problèmes complexes est très petite comparée à l'ampleur des problèmes dont la solution est nécessaire pour un comportement objectivement rationnel. (...) La première conséquence du principe de rationalité bornée est que la rationalité voulue d'un acteur lui impose de construire un modèle simplifié de la situation réelle pour y faire face. Il se comporte rationnellement par rapport à ce modèle, et un tel comportement n'est même pas approximativement optimal par rapport au monde réel ». En conséquence, les agents économiques utilisent l'heuristique plutôt que l'optimisation. Ils n'optimisent pas mais « satisfont ».

Du point de vue d'un agent, cela peut être « optimal ». De même, du point de vue de l'investissement, cela signifie que les agents peuvent ne pas réaliser (ou même tenter de réaliser) des rendements maximaux. Dans ce cas, la formation des prix ne reflète pas toutes les informations, étant donné que les agents n'ont pas tenté d'optimiser. En conséquence, les prix peuvent devenir asymétriques, ce qui pourrait entraîner une mauvaise allocation du capital.

La question du modèle est au cœur de la question des risques de transition. Les risques de transition sont peu susceptibles d'être captés par les modèles de risque traditionnels - des modèles qui sont considérés comme des représentants des risques réels. Il y a un certain nombre de raisons à cela, notamment la rupture du principe de la distribution normale associée à ces risques et le manque de données historiques (ibid.). La distribution des scénarios de transition n'est pas normale dans la mesure où elle présente un poids dans une direction - il semble y avoir un poids visuel qui entraîne la partie inférieure de la courbe vers le bas. Les scenarios suggèrent donc une distribution asymétrique dans un sens - dans le cas présent dans le sens de la probabilité liée à une voie de décarbonisation à 2° C. Naturellement, cette distribution est quelque peu « artificielle », peut-être plus d'une « distribution sociale » que d'une distribution quantifiée - le nombre de scénarios de 2° C ne témoigne pas nécessairement de sa probabilité. Mais néanmoins, comme un proxy pour la distribution, il montre un biais.

Bien que l'hypothèse de distribution normale ne soit plus aussi fondamentale qu'auparavant, elle constitue toujours la base de tous les modèles, y compris les modèles introduits par Markowitz (1952) dans le contexte de la théorie moderne du portefeuille, le modèle Arrow-Debreu (1954), le modèle d'évaluation des options Black-Scholes (1973) et des modèles plus récents du risque de crédit (voir Chatterjee 2012). Il est également utilisé par les modèles de stress test du FMI par exemple (Ong 2014).

Une raison fondamentale de l'utilisation de la distribution normale est la complexité supplémentaire qu'une distribution non normale introduit dans les modèles - une complexité potentiellement évitée au moins en partie en raison du principe de rationalité limitée. Les agents utilisent des hypothèses simplifiées pour réduire la complexité : cela peut sembler logique pour un agent qui ne cherche pas à optimiser - et donc être considéré rationnel - mais cela peut créer des biais systématiques dans les modèles qui conduisent à une tarification sous-optimale des risques.

Pour résumer: Premièrement, la caractéristique particulière des risques de transition suggère qu'ils sont susceptibles d'échouer sur le marché. Ceci est lié à la probabilité que ces risques soient susceptibles d'être des risques extrêmes à long terme, non distribués normalement. Il y a donc des raisons de penser qu'une intervention des détenteurs d'actifs à long terme et / ou des autorités de réglementation susceptibles d'être confrontés à la mauvaise allocation des capitaux associée à cette défaillance du marché pourrait être nécessaire. Naturellement, dans une perspective plus sociétale, cet appel à l'action apparaît également justifié compte tenu de l'objectif global de limitation du réchauffement climatique à 2 ° C et du rôle des investissements dans la réalisation de cet objectif.

La thèse ne prouve pas qu'il y a une mauvaise évaluation. Nonobstant, le travail de recherche a cherché à démontrer que les risques associés à la transition vers une économie bas carbone - les risques de transition - peuvent ne pas être correctement évalués et que des preuves théoriques suggèrent que cela pourrait être probable. Le défi clé devient alors, pour les investisseurs soucieux de la tarification, de mesurer leur alignement avec les objectifs climatiques comme un premier pas vers des modèles de risque financier et, comme nous le verrons plus loin, vers une réinterprétation de la notion de « portefeuille de marché ». Développer un modèle qui informe sur ce désalignement est au cœur de cette thèse.

Fondamentalement, le discours théorique présenté fournit deux angles sous lesquels les mesures autour de l'alignement des portefeuilles financiers pourraient être comprises. L'une est une interprétation plus holistique du portefeuille de marché représentant la « croyance du marché » sur les résultats futurs en ce qui concerne les voies de transition. Les investisseurs institutionnels qui cherchent à adopter une vision alternative de ce résultat ont besoin d'une base pour comparer les résultats de la transition de leur stratégie de gestion de portefeuille aux objectifs climatiques.

Une interprétation plus holistique du « portefeuille de marché » considère alors le portefeuille de marché comme dépendant de la croyance des investisseurs en ce qui concerne les résultats climatiques.

Un autre angle est que le « portefeuille de marché » dépend en fait de l'hypothèse critique d'investisseurs homogènes. Une fois cette hypothèse adoucie, soit parce que les investisseurs ne maximisent pas tous leurs utilités, soit avec des horizons de placement différents et des taux d'actualisation associés, différents investisseurs auront des portefeuilles différents, même s'ils partagent les mêmes convictions sur les flux de trésorerie futurs. C'est la raison pour laquelle ils peuvent actualiser différemment les flux de trésorerie.

Les cadres de comptabilité climatique sur les marchés financiers

La première étape vers le développement d'un cadre alternatif de diversification optimale concerne les questions de comptabilité, en particulier les cadres de comptabilité climatique sur les marchés financiers. L'origine de ces idées est liée au développement de la première empreinte carbone des portefeuilles actions cotées en 2005/2006, initiée par les investisseurs de Henderson Global en partenariat avec Trucost et Pictet AM avec Inrate. Au fil du temps, un certain nombre de nouveaux entrants sur le marché (par exemple South Pole Group, Ecofys, MSCI) ont commencé à développer des cadres d'empreinte carbone (2 ° Investing Initiative 2014).

L'analyse des principes comptables repose sur une combinaison de sources empiriques et théoriques. L'une des sources principales, et la première, implique un examen de la documentation des études de marché liées aux services comptables climatiques fournis par les fournisseurs et les consultants donnés, Ces études de marché fournissent un aperçu holistique des principes de comptabilité climatique appliqués par les investisseurs, puisque tous les investisseurs engagés dans la comptabilité climatique s'appuient d'une manière ou d'une autre sur les services des fournisseurs de données et des consultants couverts par ces études de marché. Par conséquent, une analyse de ces services fournit une vue d'ensemble relativement complète de l'état de la comptabilité et des principes de données appliqués par les investisseurs. Compte tenu de l'évolution des marchés, l'article complète, si nécessaire, l'analyse de marché par des informations complémentaires sur les développements les plus récents.

En plus d'analyser « l'offre » de la comptabilité climatique, la thèse s'appuie également sur l'engagement des auteurs auprès des investisseurs institutionnels (c'est la deuxième source). Dans le cadre de cette recherche, l'auteur a interrogé plus de 100 investisseurs institutionnels. Les entretiens n'ont pas été menés dans le cadre d'un projet de recherche spécifique et n'ont donc pas impliqué de questionnaire spécifique. Par conséquent, les résultats de l'analyse n'incluent pas les résultats quantitatifs de ces entrevues quant aux préférences ou choix comptables spécifiques. En effet, l'analyse technique des choix comptables n'est pas influencée par la popularité, mais par l'applicabilité technique. Par conséquent, l'intégration des leçons tirées de ces entrevues implique le cas échéant une discussion des approches (anonymisées si nécessaire) en ce qui concerne les principes comptables, ainsi que des mises en garde ou des défis identifiés dans ces entretiens. Cette enquête assure une couverture complète des approches en rapport avec les principes comptables et permet d'identifier les défis qui ne sont pas nécessairement obtenus par un examen théorique des principes comptables. Dans le même temps, comme souligné ci-dessus, ces entretiens ne satisfont pas aux normes de rigueur nécessaires pour tirer des conclusions indépendantes ou tirer des conclusions quantitatives.

La troisième source concerne l'application technique en utilisant des exemples de données climatiques et financières à des fins d'illustration et de test des approches, pour illustrer les implications de l'utilisation de règles comptables différentes et / ou de la faisabilité de l'une ou l'autre approche. Les éléments reposent sur les données financières de Bloomberg et les données sur l'empreinte carbone, tirées des rapports annuels, ainsi que sur les sources de données tierces, le cas échéant.

Une fois l'objectif de mesure de l'alignement des portefeuilles financiers établi et le principe comptable clé défini, la question suivante se pose évidemment quant aux mécanismes en place pour y parvenir. La question devient alors comment cela peut être mesuré. La question de l'exposition du portefeuille est particulièrement intéressante, plutôt que le calcul du risque financier associé à chaque titre. L'analyse de la mesure se concentre donc sur les paramètres au niveau du portefeuille (agrégés de bas en haut ou de haut en bas) qui reflètent l'exposition d'un portefeuille à la transition vers une économie à faible émission de carbone. Les statistiques de portefeuille peuvent être exprimées en tant que mesures de risque, ou en tant que métriques d'alignement ou « respectueuses du climat ». C'est cette série qui, en première instance, présentera un intérêt particulier.

Les données sur l'activité économique

Les données sur l'activité économique, ou « données climatiques », sont nécessaires pour identifier l'alignement ou l'exposition d'un acteur financier avec l'activité économique pouvant être associée à des scénarios à 2° C et pour informer sur l'analyse financière associée. Il peut être utilisé comme point de référence dans le contexte de l'allocation des données du scénario macroéconomique aux acteurs microéconomiques. Il existe différentes données économiques qui peuvent être utilisées pour définir l'unité climatique d'une entreprise, et peuvent être comptabilisés à quatre niveaux : l'actif physique, l'activité commerciale (sectorielle), l'entreprise et le secteur du marché. Selon la disponibilité des données sur le marché et le type d'analyse souhaité, différents niveaux peuvent être plus ou moins appropriés (Thomä et al., 2018).

Lorsqu'il s'agit d'obtenir des données sur les activités économiques, à l'exception de la R&D, qui ne peut être quantifiée qu'au niveau de l'entreprise, les principales données sous-jacentes définissant les activités d'une entreprise commencent au niveau de l'actif individuel. La discrimination des actifs individuels permet une analyse comparative régionale de l'analyse par rapport aux scénarios régionaux (lorsque ceux-ci existent par exemple pour la production d'électricité) et un lien direct entre l'activité économique par technologie et le secteur aux scénarios. Il permet également d'évaluer le risque de transition physique granulaire et les risques liés aux politiques.

Ces données au niveau des actifs peuvent provenir de canaux agrégés de reporting d'entreprise ou de bases de données d'actifs collectant des données provenant de diverses sources, notamment des communiqués de presse, des dépôts réglementaires, des enquêtes, des rapports annuels et des publications sectorielles (Weber et al., 2017). Le choix réel en termes d'approvisionnement de données est indépendant de l'application de l'analyse d'alignement de scénario à 2 ° C, c'est-à-dire que les deux options sont en théorie acceptables. En pratique cependant, les données sur les actifs sont nettement plus appropriées. Les rapports d'entreprise au niveau des actifs physiques sont souvent incohérents en termes de rapidité d'information, de principes comptables et de couverture en termes de géographie et de type d'actif et / ou d'entité comptable (Dupré et al., 2015). Ceci limite l'applicabilité universelle de l'analyse de scénario elle-même, et peut ainsi limiter son rôle de fournisseur de prospectus de marché ou global. D'autre part, la base de données créée par les organisations de marché permet une analyse de scénarios plus complète pour les portefeuilles financiers types en raison de la standardisation possible et du choix des règles comptables, étant activement maintenue et incluant souvent des activités prospectives (Weber et al. 2017, Caldecott et Kruitwagen, 2017).

Bien évidemment, ce type de données n'est pas exempt de défauts. Principalement ceux-ci se rapportent à l'absence d'audit formel transparent des données sous-jacentes qui conduit à différentes bases de données ont des informations contradictoires sur la propriété d'un actif donné. En outre, les ensembles de données peuvent être limités à des secteurs industriels particuliers et ne sont pas nécessairement harmonisés entre les différentes activités commerciales, ce qui rend la consolidation pour les entreprises diversifiées ou les grandes entreprises coûteuse et techniquement difficile à entreprendre. À la connaissance des auteurs, l'évaluation de la qualité des informations sur les entreprises au niveau des actifs n'a été réalisée que dans une seule étude (Glattfelder et Hayne, 2017), et aucune base de données n'a été réalisée à ce jour. Les données au niveau des actifs forment alors la base du modèle de portefeuille à 2 ° C développé dans cette thèse.

Les principes dans la bas du modèle de portefeuille à 2 ° C

Le modèle de portefeuille à 2 ° C permet de mesurer le delta entre l'activité économique d'un portefeuille financier et l'activité économique souhaitée qu'il doit contenir pour être cohérent avec un monde à 2 ° C ou bien en dessous de 2 ° C. Il le fait en quantifiant l'activité économique sur la base des actifs économiques détenus ou financés par les instruments financiers du portefeuille, en calculant une relation entre les deux sur la base d'un ensemble de principes comptables décrits plus haut. Cette exposition d'un portefeuille est comparée à une exposition souhaitée représentée par un « benchmark 2° C », qui retrace la diversification optimale qu'un portefeuille prendrait dans une transition de 2° C, calculée sur la base d'une combinaison de scénarios économiques à 2° C et leur ajustement à des classes d'actifs spécifiques, des zones géographiques d'investissement et des horizons temporels. Ainsi, le benchmark 2° C représente une diversification optimale par rapport à un horizon temporel, un scénario économique, une classe d'actifs, l'exposition géographique d'un portefeuille, un ensemble de principes comptables, des données économiques sous - jacentes et leur périmètre.

Le modèle comprend un certain nombre de caractéristiques clés et de caractéristiques distinctives qui sont brièvement résumées ci-dessous:

- Le modèle ne prédéfinit pas les tendances ou les chocs macroéconomiques, mais crée plutôt un « logiciel de traduction » qui fait correspondre les tendances macroéconomiques prévues et les chocs aux portefeuilles financiers. Il ne repose donc pas sur le développement de ces tendances économiques et peut être utilisé pour tester toute hypothèse macroéconomique.

- Le modèle évalue l'alignement de 2° C des portefeuilles financiers avec un horizon temporel, une période de prévision de 5 ans. L'horizon temporel est limité à l'horizon temporel de la planification des dépenses en capital pour lesquelles les données peuvent être suivies à un niveau significatif. Des évaluations à plus long terme sont prévues à mesure que le modèle s'étend aux indicateurs liés au risque, ce qui nécessite un ensemble d'hypothèses supplémentaires.

- Le modèle évalue l 'exposition technologique des portefeuilles dans une gamme de secteurs d'activité et de secteurs pertinents pour le climat. À ce stade, il couvre les combustibles fossiles, l'énergie et les transports (véhicules de transport de passagers légers, avions). Les indicateurs sont pris en compte soit dans les termes « exposition globale », soit dans les « termes de la trajectoire » (investissements, ajouts / retraits d'actifs, changements dans les profils de production).

- Le modèle fournit, si possible, des données prospectives au niveau des actifs pour les technologies clés, afin de fournir des évaluations spécifiques à la géographie pour des segments d'activité spécifiques mappés au niveau de l'entreprise. Il contourne ainsi chaque fois que possible les rapports rétrospectifs au niveau de l'entreprise, bien que ces rapports puissent être utilisés pour valider des paramètres prospectifs (par exemple les émissions de GES).

- Le modèle élabore des repères scientifiques spécifiques au marché financier qui comparent le rendement du portefeuille non seulement aux repères du marché existant, mais aux repères associés aux voies de décarbonisation.

- Le modèle se concentre sur l'évaluation de classes d'actifs spécifiques, l'évaluation étant limitée à ce stade aux instruments de crédit (en particulier aux obligations d'entreprises) et aux fonds propres (notamment les fonds propres côtés, bien que applicables aux private equity).

- Compte tenu de l'accent mis sur les technologies et le climat, l'analyse se limite aux parties du portefeuille exposées directement aux technologies pertinentes. Il ne couvre donc qu'environ 20-30% du portefeuille moyen en termes d'actifs sous gestion, bien qu'environ 70-80% des impacts du portefeuille sur les GES.

La traduction des tendances de la transition économique en marchés financiers nécessite quatre types de données: i) données de scénario, ii) données d'activité économique, iii) données sur le marché financier et la propriété et enfin, si l'on cherche à mesurer la tendance d'un acteur financier spécifique, iv) données sur les composantes du portefeuille financier.

Le modèle de portefeuille à 2 ° C – Les formules pour les deux approches développe

Au cours de l'application avec les institutions financières, deux approches différentes se sont matérialisées, qui sont résumées dans les équations ci-dessous. Il vaut la peine de les souligner brièvement en termes descriptifs.

La première approche suggère de mesurer l'alignement de 2° C d'un portefeuille financier à un point t futur par rapport à ce qu'on appelle ici un « benchmark 2° C ». Cette approche est fondamentalement une extension des principes traditionnels de base à la théorie moderne du portefeuille, où la diversification optimale future est mesurée par rapport à un objectif non financier mais lié au climat. Elle consiste à mesurer le delta de l'exposition globale du portefeuille à une unité climatique, l'exposition au marché étant soumise à une transition de 2° C. L'exposition au marché sous une transition de 2 ° C représente ici l'évolution attendue du marché défini, qui peut être délimitée de différentes manières, comme l'application de différents repères traditionnels (marché boursier, économie, marché boursier régional, ensemble de portefeuilles de pairs, etc.), sous une transition de 2 ° C.

La deuxième approche peut être qualifiée d'« approche trajectoire », où la mesure ne compare pas l'exposition absolue à un point futur à l'exposition absolue d'un indice de référence du marché, mais cherche plutôt à comparer deux taux de variation, à savoir le taux de variation du portefeuille par rapport à l'unité climatique, et le taux de variation nécessaire sous une transition de 2 ° C.

Les équations de base régissant les deux approches peuvent être résumées par les équations (1) et (2) pour un portefeuille, bien que le concept puisse également être étendu à une analyse au niveau de l'entreprise,

$$(1) \quad y = \frac{u^x}{u^{bench}}$$

$$(2) \quad y^{traj} = \frac{u_t^x - u_{t0}^x}{u_t^{bench} - u_{t0}^{bench}}$$

où u représente une unité climatique définie comme l'une des trois unités climatiques clés basées sur la taxonomie développée par Dupré et al. Ces trois unités sont soit des émissions de gaz à effet de serre, des mesures vertes / brunes (produits et services à faible émission de carbone ou à haute teneur en carbone), soit des notes qualitatives, selon le choix de l'activité économique et les scénarios. En principe, si l'accent est mis ici sur les portefeuilles financiers, l'unité climat peut être calculée au niveau de l'entreprise, du portefeuille individuel ou d'un groupe de portefeuilles (par exemple, le marché boursier coté).

À son tour, u^{bench} est la valeur pour être compatible avec un résultat climatique cible / le scénario. Ainsi, lorsqu'il est appliqué en conjonction avec un objectif climatique de 2 ° C, il est conçu pour refléter une exposition de référence conforme à l'objectif de l'Accord de Paris.

L'unité climatique du portefeuille, peut être calculée comme suit

$$(3)\, u^x = \sum_i^f \left(\frac{p_i}{a_i} \frac{u_i^{issuer}}{n}\right)$$

où p est la valeur de l'instrument i dans un portefeuille avec un total d'instruments f, a est le facteur d'allocation qui alloue l'activité économique de l'instrument i au portefeuille. u_i^{issuer} est l'unité climatique de l'émetteur de l'instrument, et *n* est le facteur de normalisation dans les cas où l'unité climatique de l'entreprise est normalisée sous une forme quelconque.

La logique de l'équation peut être expliquée comme suit. La définition de l'unité climatique du portefeuille nécessite l'allocation des unités climatiques associées aux émetteurs des instruments du portefeuille par une règle fixe au portefeuille. Ce facteur de répartition est fonction à la fois de la valeur de l'instrument de l'émetteur dans le portefeuille et d'un facteur qui détermine comment ce poids doit être mis en contexte. Un facteur simple ici est le poids total du portefeuille, créant essentiellement un facteur de répartition qui distribue l'unité climatique de l'émetteur au portefeuille en fonction du pourcentage que l'instrument associé représente dans le portefeuille. L'étalonnage de ce facteur d'attribution sera discuté plus en détail ci-dessous.

D'un autre côté, l'unité climatique doit être allouée. Par souci d'exhaustivité, un facteur de normalisation est ajouté, car l'unité climatique peut être normalisée dans certains cas. Un exemple simple où la normalisation peut être pertinente est l'endroit où l'unité climatique du portefeuille est censée représenter une intensité pondérée des émissions de GES de la production d'énergie, par exemple. Dans ce cas, l'unité climatique de l'émetteur doit être le total des émissions de GES par rapport à la production totale d'électricité, où la production d'énergie totale ne représente pas une unité climatique, mais un facteur de normalisation par lequel l'unité climatique est normalisée. Par ailleurs, la comparaison de la propriété absolue de l'énergie renouvelable entre deux portefeuilles ne nécessiterait pas de normalisation. Par extension, l'utilisation de ce facteur de normalisation est fonction de l'analyse exacte souhaitée. Le facteur d'allocation est déterminé par l'approche de l'analyse, à laquelle nous considérons ici deux types fondamentaux: l'approche du bilan (a^{bl}) et l'approche de la pondération du portefeuille (a^{wt}). Encore une fois, il est pertinent de décrire d'abord la logique des deux avant de plonger dans les équations. En termes simples, l'approche du bilan répartit l'unité de climat de l'instrument de l'émetteur en fonction de la propriété du portefeuille de tous les instruments en circulation de l'émetteur. Cette approche peut être considérée comme représentant une logique de « responsabilité ».

Comme il sera indiqué plus en détail ci-dessous, la responsabilité peut être fonction de la propriété du portefeuille dans tous les instruments en circulation de cette classe d'actifs (par exemple, la propriété d'actions), mais on peut adopter une vision plus large. L'approche portefeuille-pondération répartit à son tour les unités climatiques en fonction de la part de l'instrument dans le portefeuille, créant ainsi une unité climatique pondérée en fonction du capital attribué par le portefeuille à différents instruments.

La principale différence entre les approches étant l'allocation par pondération de portefeuille, définie uniquement par la construction du portefeuille, tandis que l'approche bilan considère le volume relatif de chaque instrument du portefeuille avec la taille ou la valeur respective de l'entreprise ou de la classe d'actif. Les équations régissant chaque approche sont résumées comme suit :

$$(4)\, a^{bl} = \sum_i^g p_i$$

$$(5)\, a^{wt} = \sum_i^h \sum_i^k p_i$$

où g représente le nombre d'instruments dans une classe d'actifs et h représente le nombre total de classes d'actifs émises par l'entreprise ou détenues dans le portefeuille sous-évaluation.

Par exemple, dans le cas de l'évaluation de l'action avec l'approche du bilan, cela peut représenter les actions de l'entreprise en cours, étant la somme de tous les capitaux propres sur chaque instrument de capitaux propres, émis par l'entreprise émettrice de l'instrument. C'est alors égal à la part de propriété que le portefeuille a dans la valeur, et le produit avec représente la propriété de l'unité climatique de l'émetteur de l'instrument. Finalement, u^{port} représente alors la propriété totale du portefeuille. Le concept d'émetteur peut également être étendu à tous les instruments financiers, tels que la valeur d'entreprise de l'entreprise ou un autre sous-ensemble d'actifs en circulation (par exemple, dette à long terme plus fonds propres).

Le principal problème avec ce facteur de répartition est que lorsqu'il est étendu hors des fonds propres, où les pourcentages de propriété peuvent être calculés indépendamment des variations des prix des actifs financiers, des biais de prix peuvent être introduits en relation avec le mouvement des prix des actifs, un mouvement qui n'est pas nécessairement liées à des changements dans les dépenses en capital ou les plans de production. Cela peut entraîner un biais et une incertitude quant à l'action requise du propriétaire ou du gestionnaire du portefeuille. En cas de prise en compte de la valeur de prix, cette fluctuation est déterminée par l'évolution des prix relatifs du marché (Thomä et al., 2018).

L'approche alternative de pondération du portefeuille calcule les intensités relatives de l'exposition du portefeuille à différents produits et services, et non le souhait de mesurer la propriété absolue. Comme l'allocation est basée sur la valeur relative de chaque instrument du portefeuille uniquement, les portefeuilles des catégories d'actifs peuvent être examinés conjointement. Ici, un seul type d'option peut être envisagé, à savoir la taille globale du portefeuille.

Il convient de noter que, intuitivement, les unités absolues calculées en utilisant l'approche portefeuille-poids peuvent ne pas être significatives. Par exemple, un portefeuille qui détient exclusivement un émetteur de pétrole et de gaz se verra attribuer 100% de l'unité climatique de cet émetteur, même si la taille du portefeuille n'est que de 100 $. Dans le même temps, les approches de pondération sectorielle décrites plus en détail ci-dessous peuvent contextualiser la figure avec un point de référence pour mettre en évidence l'intensité relative de l'exposition. De même, dans le cas du secteur de l'électricité, les intensités relatives des énergies renouvelables des différentes sociétés peuvent être pondérées en utilisant l'approche du portefeuille pour mettre en évidence les choix d'allocation de capital du gestionnaire de portefeuille.

En résumé, le cadre décrit jusqu'à présent se penche sur la façon de calculer l'unité climatique du portefeuille. La section suivante examinera comment cette unité climatique peut être évaluée dans le contexte d'une analyse de scénario à 2 ° C.

L'indice de référence, doit être exprimé dans la même unité climatique que u_t^x, et est calculé comme suit

$$u_t^{bench} = s + e_t \quad (6)$$

où s représente le point de départ de l'indice de référence quand t=0, et e_t la voie de décarbonisation, c'est-à-dire le changement s à une période t pour être cohérent avec l'objectif climatique 2° C.

s peut être calculé de trois manières différentes, en fonction de la normalisation souhaitée du portefeuille, équations (7), (8) et (9) ci-dessous

$$(7)\, s^{p} = \frac{\sum_i^f p_{t0}}{\sum_i^j p_{t0}^{market}} u_{t0}^{market}$$

où j est le nombre d'instruments sur le marché,

$$(8)\ s^{u} = \frac{\sum_i^k u_{t0}^{x}}{\sum_i^l u_{t0}^{market}} u_{t0}^{market,}$$

où u_{t0}^{port} et u_{t0}^{market}est l'unité climatique initiale agrégée pour le portefeuille et le marché calculée par l'équation (3), qui est additionnée au nombre de chaque technologie représentée sur le marché, k, et le portefeuille, l,

$$(9)\, s^{sec} = \frac{\sum_i^m p_{t0}}{\sum_i^n p_{t0}}$$

Où m se trouve être le nombre d'instruments dans le portefeuille des émetteurs classés dans une activité / un secteur d'activité spécifique, avec n le nombre d'instruments de tous les émetteurs classés sous cette même activité / secteur d'activité spécifique sur le marché.

Alors que les trois options peuvent être appliquées, le choix entre l'une ou l'autre concerne à la fois le secteur et l'objectif de l'analyse. L'équation (7) calcule si le portefeuille surpondère ou sous-pondère une unité climatique en termes absolus, indépendamment des expositions aux autres unités climatiques. Il peut donc être plus pertinent pour les secteurs et les produits où le scénario fait lui-même un commentaire sur l'évolution de l'activité elle-même.

Par exemple, dans le cas des combustibles fossiles (production de pétrole, de gaz et de charbon), le scénario de 2° C suggère généralement une diminution de la capacité de production absolue et donc une baisse de la valeur d'un portefeuille ou d'une entreprise.

Par exemple, dans le cas du secteur de l'énergie et de l'automobile, alors que les différents scénarios supposent des niveaux agrégés de capacité de production dans le temps, le principal moteur du scénario est le passage des carburants à haute teneur en secteur de l'énergie et le passage de groupes motopropulseurs à haute teneur en carbone à des groupes motopropulseurs à faible émission de carbone dans le secteur de l'automobile. Dans ce contexte, il peut être pertinent de comprendre non seulement le degré d'exposition de la production d'énergie renouvelable à l'énergie électrique totale, mais aussi le poids des énergies renouvelables dans l'énergie thermique du portefeuille.

Le choix pour s^{sec}, étant donné qu'il s'agit d'un proxy sectoriel plus brutal, apparaît comme une solution de second choix où les deux autres options ne peuvent pas être appliquées pour des raisons techniques sans créer de biais, par exemple dans le calcul d'un point de départ capacité dans les portefeuilles d'obligations de sociétés lors de l'application de la méthode du portefeuille-poids.

Pour calculer le changement nécessaire à l'indice de référence, e_t on définit

$$(10) \qquad e_t = \Delta u_t^{scenario} \frac{u_{t0}^{x}}{u_{t0}^{market}} c$$

où

$$(11) \qquad \Delta u_t^{scenario} = \frac{u_t^{scenario} - u_{t0}^{scenario}}{u_{t0}^{scenario}}$$

où $u_t^{scenario}$ représente l'unité climatique de l'ensemble de l'économie (par exemple, la capacité de production associée à un produit ou service spécifique), par le scénario de décarbonisation, et c est une constante pour décrire tout ajustement de la part de marché au fil du temps. Cela pourrait être important dans les secteurs d'activité où la part de marché des agents économiques devrait évoluer au fil du temps. Par exemple, le cas de la production d'énergie renouvelable, où, dans certaines régions, la capacité de production d'électricité des ménages a commencé à se propager sur le marché de l'énergie électrique en raison des réponses différenciées des deux participants à certaines incitations gouvernementales. Dans ce cas, c_t pourrait être utilisé pour tenir compte de la poursuite des tendances historiques, et explicitement dans cet exemple, compte pour la réduction de la part de marché globale de puissance de l'énergie cotée de l'énergie renouvelable totale.

L'analyse est quelque peu compliquée par le fait que, pour les technologies à faible émission de carbone, il peut être pertinent de démêler la part de marché de la technologie et la part de marché dans l'activité commerciale de manière plus générale. Ainsi, si un service public a une capacité de 10 GW de puissance électrique, mais une puissance électrique nulle, prendre simplement la part de marché dans l'énergie renouvelable (dans ce cas, zéro) suggérerait qu'une telle utilité ne devrait pas concerner des énergies renouvelables. C'est absurde car une telle stratégie attribuerait l'entière responsabilité des ajouts de capacités aux leaders historiques et absoudrait les retardataires historiques (sans parler de la baisse de la part de marché globale au fil du temps). D'un autre côté, une compagnie d'électricité qui possède 10 GW d'énergie électrique, mais pas d'électricité alimentée au charbon, ne serait pas en mesure de retirer de l'électricité alimentée au charbon. Cette dichotomie entre technologies à haute teneur en carbone et faibles émissions de carbone nécessite un étalonnage du modèle pour refléter cette distinction.

Pour résoudre cette tension, le modèle contrôle si l'unité climatique est associée à un produit ou à un service à haute teneur en carbone ou à faible émission de carbone par une extension de l'équation (10) à l'équation (12) ci-dessous (12)

$$(12) \qquad e_t = \Delta u_t^{scenario} \, \frac{f(d, u_{t0}^{x})}{f(d, u_{t0}^{market})} c$$

où

$$(13) \qquad f(d, u_{t0}^{x}) = \frac{(d-1)}{-2} \left(u_{t0}^{x,sector} - u_{t0}^{x} \right) + u_{t0}^{x}$$

et

$$(14) \qquad f\left(d, u_{t0}^{market}\right) = \frac{(d-1)}{-2} \left(u_{t0}^{market,sector} - u_{t0}^{market} \right) + u_{t0}^{market}$$

où $u_t^{x,sector}$ et $u_t^{market,sector}$ représente le volume total de u_t^{x} and u_t^{market}, respectivement, de tous les produits et services dans une activité pour le portefeuille et le marché (par exemple, la capacité totale de production, en MW, pour tous les types d'actifs énergétiques - renouvelables, charbon, gaz, etc.), et d est une valeur fictive qui prend la valeur 1 si u est associé à un produit ou service à haute teneur en carbone et -1 si est associé à un produit ou service à faible émission de carbone.

Le principal défi de modélisation associé à chaque type d'évaluation consiste à cartographier les tendances macroéconomiques et les chocs affectant les portefeuilles financiers et les entreprises. Le modèle utilise une simple hypothèse de « partage équitable » pour faire correspondre ces tendances aux entreprises et aux portefeuilles financiers. Cette hypothèse d'attribution équitable stipule que les impacts économiques sont mis en correspondance avec les portefeuilles financiers et les sociétés sous-jacentes en fonction de la part de marché que ces portefeuilles et entreprises possèdent dans la technologie ou le marché concerné par cet impact.

La part de marché future est calculée en fonction de la diminution ou de l'augmentation du profil de production dans les 25 prochaines années, en fonction de la tendance macroéconomique. Si la production est destinée à augmenter, la part équitable est calculée sur la base de la part de marché totale du produit (par exemple capacité installée, etc.). Cette approche est appelée la « part équitable du marché ». Si la production est destinée à diminuer, la part équitable est calculée sur la base de la part de marché totale du combustible / de la technologie spécifique (par exemple, la production de charbon, la puissance installée du charbon). Cette approche est appelée la « part équitable technologique ». Cette distinction a été choisie car l'application d'une part de marché équitable aux technologies en déclin peut finalement donner des résultats négatifs (puisque la part de marché pourrait être supérieure à la part équitable technologique) et parce que les portefeuilles ayant des augmentations de production retardées ne doivent pas être considérés comme le faire à l'avenir. En théorie, le modèle pourrait appliquer la part équitable de la technologie pour les technologies à la fois croissante et décroissante, un choix qui n'a pas été fait dans l'itération actuelle.

L'utilisation de l'approche de la part équitable pourrait être contestée car elle ne tient pas compte des réalités importantes du marché qui détermineront la performance de chaque entreprise dans différents scénarios macroéconomiques. Les approches alternatives impliquent des évaluations ascendantes de chaque entreprise individuelle. Bien que techniquement faisable, c'est beaucoup plus cher et techniquement complexe. Une autre option pour les compagnies pétrolières et gazières consiste à utiliser des courbes de coûts pour cartographier les impacts sur les producteurs à faible coût et à coût élevé. Le défi de cette approche est à la fois la qualité des données et la logique selon laquelle les coûts sont les principaux facteurs. Néanmoins, une telle approche de la courbe des coûts est susceptible d'être plus précise qu'une simple hypothèse de partage équitable et peut être appliquée à l'échelle avec des ensembles de données précis où ils incluent des informations sur les coûts de production. Ce serait cependant limité aux carburants fossiles.

Feedback pour le model

Dans le cadre du test routier, des retours ont été recueillis via des entretiens bilatéraux de plus de 30 investisseurs et dans le cadre d'une enquête anonyme auprès de 27 investisseurs (voir Annexe 1 pour les questions d'enquête). Des commentaires ont également été recueillis auprès d'un certain nombre d'intervenants externes, notamment des universités, des groupes de réflexion et des décideurs. Cette section résume le retour d'expérience de ce processus, en reliant les retours qualitatifs et quantitatifs. Étant donné que l'enquête a été réalisée de manière anonyme, une probabilité de biais d'échantillonnage dans les résultats ne peut être exclue.

23 des 27 (85%) investisseurs interrogés ont déclaré que le modèle était « tout aussi pertinent » ou « plus pertinent » que les approches existantes . Deux investisseurs ont répondu que le modèle était moins pertinent ; mais ils ont déclaré qu'ils étaient encore susceptibles de l'utiliser. L'un des deux investisseurs a suggéré son utilisation pour « identifier les entreprises à s'engager dans les futurs plans d'affaires ». L'autre investisseur a critiqué la portée limitée mais a suggéré qu'il ou elle l'utiliserait lors de l'expansion.

24 investisseurs sur 27 (89%) ont déclaré qu'ils étaient susceptibles d'utiliser l'évaluation dans leurs décisions d'investissement, soit maintenant, soit dans le cadre d'un outil de portfolio sur une base de données financière. Les commentaires qualitatifs suggèrent que le cas d'utilisation est très différent selon les investisseurs, certains le considérant comme un outil d'engagement («informer les discussions [avec les entreprises] sur les risques d'actifs / climatiques en relation avec les plans futurs»). sélection de titres ("conception d'objectifs liés au climat"). Parmi les trois investisseurs qui ont déclaré qu'ils n'étaient pas susceptibles ou très peu susceptibles d'utiliser l'évaluation, un a écrit qu'il n'utilisait que des gestionnaires externes et était donc plus susceptible d'utiliser l'outil « comme un contrôle ». Un autre investisseur a critiqué la portée actuelle en arguant de la nécessité de l'étendre à d'autres secteurs et catégories d'actifs, mais a néanmoins trouvé l'outil « plus pertinent » que leurs évaluations existantes. Le dernier

investisseur a donné des commentaires écrits sur le fait qu'ils « l'ont utilisé parce qu'il est considéré comme l'outil le plus pertinent sur le terrain en ce moment et nous allons attendre qu'il s'étende aux marchés émergents et aux différentes classes d'actifs ».

Au final, les éléments positifs ou forces identifiées en ce qui concerne le cadre d'évaluation du portefeuille de 2 ° C sont les suivants :

- Les investisseurs ont souligné comme innovation essentielle la nature prospective de l'évaluation, en particulier par rapport à la classe actuelle de données sur l'empreinte carbone. Les données prospectives sont un prérequis pour comparer les portefeuilles aux trajectoires économiques (voir ci-dessous) et relier les portefeuilles aux risques futurs;

- L'utilisation de données de haute qualité sur les actifs est une autre caractéristique essentielle du modèle, réduisant les éléments trompeurs des données liées au climat, évitant dans une large mesure les lacunes dans les rapports d'entreprise et permettant des évaluations spécifiques aux régions;

- L'analyse sectorielle a permis une étude plus granulaire que la taille unique de haut niveau de tous les indicateurs. Alors que la limitation à certains secteurs était considérée comme une lacune par certains investisseurs, le modèle couvre environ 80% des émissions de GES d'un portefeuille type. Il aborde donc les secteurs clés du point de vue climatique;

- Le développement d'un benchmark scientifique à 2° C est apparu comme une innovation majeure, permettant aux investisseurs de se comparer non seulement au marché, mais aussi aux objectifs climatiques et aux engagements de l'Accord de Paris.

- L'utilisabilité pour l'engagement et la sélection de titres est apparue comme un avantage clé pour les investisseurs cherchant à trouver des évaluations significatives pour toutes les entreprises exposées aux infrastructures liées au climat pour les carburants fossiles, l'énergie et le transport automobile. Bien que cela ait été décrit comme une rétroaction positive, les investisseurs ont également indiqué qu'ils ressentaient le besoin de plus de conseils sur l'utilisation du modèle.

Voici un résumé des principaux défauts identifiés dans le cadre du modèle:

- L'une des faiblesses les plus fréquemment citées du modèle dans les commentaires écrits anonymes a été sa couverture sectorielle limitée, compte tenu de sa concentration sur environ 20% du portefeuille. Le modèle manque les secteurs d'activité clés (p. Ex. Autobus, bicyclettes, covoiturage, chaîne d'approvisionnement en amont, etc.).

- Les investisseurs ISR et thématiques ont fait valoir que le modèle ne pouvait pas saisir pleinement leurs inclinaisons thématiques.

- Les résultats du modèle sont complexes et ne peuvent être distillés en un seul nombre

Introduction

Financial markets provide the traffic lights and street signs of the yellow brick road. In setting the price for and determining the availability of capital across the universe of investment decisions taken by companies, households, and governments, their signals govern what moves and what doesn't, and in which direction the journey leads us. Of course, standing by the road, they do not decide the nature of capital demand that comes their way. And indeed, nor will they in most cases deliver the final investment decision at the end of the journey. At the crossroads of supply and demand of capital however, they are the ultimate judge and jury, wielding near absolute power.

Their prominence thus makes them a critical linchpin for influencing the direction of travel of the global economy. Arguably the most fundamental challenge for our generation is ensuring that that direction of travel is consistent with limiting global warming to well below 2°C. The best available scientific evidence suggests that anthropogenic climate change represents a fundamental threat to our economy, our health, our political and social order, and the stability of the planet.

Limiting it is the precondition for addressing our broader political and social challenges. The key question then is ensuring that financial markets appropriately respond to and contribute to achieving the objective of limiting global warming – specifically and ideally to the extent that is consistent with climate change well below 2°C above pre-industrial levels. This is the objective defined in the Paris Agreement, the international climate accord defining the political mandate (UNFCCC, 2015). While even this degree of change is undesirable based on the scientific evidence, it is only in the art of the possible, not necessarily the desirable, that humans have any hope of excelling.

This thesis seeks to develop a framework to measure whether financial markets are indeed allocating capital in a way that is consistent with that objective. In doing so, it seeks to restate or perhaps more specifically expand the framework that currently governs investment decisions in financial markets, based on modern portfolio theory. It places the challenge of aligning financial markets with climate goals, not as an adjunct to or tweaking of, but rather a fundamental part of this theory and specifically the concept of optimal diversification.

Appropriately, the philosophical point of departure for this thesis is not then the literature on climate change. Indeed, perhaps somewhat controversially, for the objective of this thesis, the extent to which anthropogenic climate change is both a real and material phenomenon is entirely secondary. Consistent with this premise, the thesis does not cite a single study that documents either widespread climate change detected in temperature observations on the planet's surface, free atmosphere, and oceans, nor the extent to which anthropogenic greenhouse gas forcing driven by the combustion of fossil fuels (and other human activities) is causing these changes.

That is not to say that the author does not find such evidence both compelling and convincing, as highlighted in the introductory paragraphs to this thesis. Rather, this thesis posits itself as a translation software that can help reconnect finance with the real economy and societal objectives. The international political community has committed itself to limiting global warming to well-below 2°C as part of the Paris Agreement and in Art. 4.1 defines the way to get there in achieving "a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty." (UNFCCC, 2015)

The question then is how financial markets can align with this societal objective – independent of whether this societal objective is indeed at the end of the day desirable or not, from the perspective of the author or otherwise. What matters is creating a model that can speak to the consistency of financial portfolios with economic and societal objectives. Bringing and applying this infrastructure to the question of climate objectives then is a way to pilot this framework and make it practical. In doing so, it considers a contribution to the broader question of investment and portfolio theory. From this point onwards, the over-arching political discussion on climate issues will not be discussed further.

In looking to the academic canon finance, the thesis argues two key points. The first is that optimal diversification for a financial institution does not only relate to the distribution of assets in a portfolio consistent *with the prices these assets have* but also with the economic activity associated with these assets. The second point is that optimal diversification cannot just be described in terms of *financial optimisation*, but also in response to other objectives – notably in this case that of allocating capital in a way that is consistent with climate goals.

On the basis of these two points, the thesis builds on traditional modern portfolio theory to develop a new way to think about optimal diversification, beyond financial to climatic concerns and beyond asset prices to economic activity considerations. Most of the academic literature over the past half-century has sought to either abandon modern portfolio theory or 'tweak it', arguing for the presence of exceptions or beta factors. This thesis does not try to achieve this.

Instead, it restates modern portfolio theory in the light of optimal economic diversification and alternative objectives.

In terms of structure, the thesis develops how this framing can sit on the traditional modern portfolio theory (Chapter 1) and why the traditional theory may not capture this new objective (Chapter 2). It highlights the connection between financial markets and climate goals (Chapter 3) and the key accounting principles that can govern this relationship (Chapter 4). It then shows how these have been applied to date (Chapter 5) and the associated shortcomings. The thesis subsequently introduces an alternative framework, building on key principles of modern portfolio theory (Chapter 6) and shows how this can be applied in practice (Chapter 7), as well as the challenges and shortcomings that still exist. The thesis concludes with a discussion of the potential impact of financial market decisions on the basis of the new framework (Chapter 8) and regulatory and policy implications (Chapter 9). Chapter 10 discusses where the future may take us and concludes the thesis.

The model described here benefits from having been road-tested by over 250 financial institutions to date, three financial supervisory authorities, and one government. An estimated €10 trillion in assets under management have been tested to date using the model. It builds on data covering around 90% of corporate owned power plants, oil & gas fields, coal mines, cement plants, steel plants, ships, airplanes, and car factories. It does not only provide one way, but rather a general accounting framework that accommodates different tailored research questions, approaches, concepts, and investment beliefs.

In this, it recognizes that the research question it posits – the alignment of financial portfolios and optimal diversification consistent with a net zero transition – actually hides a range of research questions that require different approaches. It recognizes that just as street lights and traffic signs guide traffic for all types of transport modes across the world, so too models must be adaptable for rain, sleet, or snow. This is the journey this thesis undertakes.

Part 1
Two roads diverged in a wood…
From financial markets to climate goals

1. A trip down memory lane: The evolution of modern portfolio theory

1.1 A brief archaeology of investment theory

Describing the way money gets invested today requires a brief tour down memory lane. Surprisingly, the 'science' of how money gets invested is quite recent. Before the 1920s, investment activity largely consisted of two, somewhat cliched, categories. The 'captains of industry', white elderly men directing the allocation of capital and individually capable of bailing out financial sectors, as famously the case with JP Morgan in the Panic of 1893 (Kindleberger, 1978). The other side of the story is littered with a series of victims of frauds and hoodwinked individuals, whether in the infamous 'Tulip mania' in the Netherlands, the 'Mississippi bubble' in France (Kindleberger, 1978), or the series of frauds recently documented in the book 'Fraud: An American History' by Edward J. Balleisen (Balleisen, 2017).

Arguably, both of these categories involved investing largely on wit, insider information, fraud, dumb luck, and the odd analytical and strategic decision-making, with the leading investors of the day often directly involved in their enterprises. The 'robber barons' of the US Gilded Age come to mind – Vanderbilt, Rockefeller, Astor. The state of the art by the end of the 19th century had thus not significantly graduated from the time of the Italian Renaissance polymath Gerolamo Cardano, who concluded that the "The greatest advantage in gambling lies in not playing at all" (Cardano and Gould, 2015).

The 1920s altered the landscape of investing. Technology led to both a democratisation of capital markets regarding access to the individual middle-class worker, as well as increasing disintermediation, with the sums and volume of trading no longer easily manipulated by individuals. Capital markets played an increasing role in how capital was intermediated in the 1920s. This shift in practice triggered a growing need for an understanding of the principles of investment. It is only from the 1920s and 1930s onward that one can properly speak of investing. The pre-science thinking of investing is perhaps best encapsulated in the quote by JP

Morgan in testimony before the house Committee on Banking and Currency in 1912 (Peeler, 2010):

Samuel Untermeyer: "Is not commercial credit based primarily upon money or property?"

Morgan: "No, sir; the first thing is character."

Untermeyer: "Before money or property?"

Morgan: "Before money or anything else. Money cannot buy it."

The genesis of investment theory proper then can arguably be traced to the seminal textbook Security Analysis by Benjamin Graham and David Dodd, first released in 1934 (Graham and Dodd, 2009). Graham and Dodd argue that maximising return in investing is a function of information, making them the intellectual fathers of what is today called 'value investing', perhaps most popularly associated with the name of Warren Buffett. The idea is that capitalising on an informational advantage in the pricing of assets generates returns, buying under-valued companies and selling over-valued companies. It is this work that also first created the distinction between speculation and investment, extending the scope of investing to both bonds and equities, which had prior been primarily seen exclusively as a 'speculation' vehicle (Chamberlain and Hay, 1931). Graham is then also credited with the quote "The individual investor should act consistently as an investor and not as a speculator."

Indeed, it is this distinction that makes Security Analysis stand out in the literature. Obviously, Graham and Dodd were not the first to think analytically about security prices and speculation. Investment manager Edgar Smith published "Common Stocks as Long-Term Investments" in 1924 espousing equity investments (Smith, 2015). Gibson in 1889 perhaps first introduced the 'wisdom of the crowds' thinking into investment analysis – a pre-cursor of the efficient market hypothesis – by arguing that "shares become publicly known in an open market, the value which they acquire may be regarded as the judgement of the best intelligence concerning them." (Gibson, 1889) Louis Bachelier would become famous a half century after publishing his thesis on the theory of speculation in 1900 (Bachelier, 1900).

The pioneering work by Graham and Dodd was soon followed by the "The Theory of Investment Value" published in 1938 by Williams (Williams, 1938), which introduced the concept of a security being worth the sum of its future discounted cash flows, developing the

Divided Discount Model. A security's "investment value is defined as the present worth of future dividends, or of future coupons and principal (…) of practical importance to every investor because it is the *critical* value above which he cannot go in buying or holding without added risk." In effect, Williams formalised the security analysis thinking by Graham and Dodd, while building on Irving Fisher's Theory of Interest *(Fisher, 1965)*, borrowing notions of discounting the future, an element that will become critical when returning to the question of aligning financial markets with climate goals.

Williams however added a crucial element to this investment value discussion, an idea that would become critical in future investment theory and indeed come to shape much of modern investing in capital markets, reaching an intellectual dominance perhaps unparalleled in any other discipline. Williams, in somewhat of an aside, came to the somewhat tautological conclusion that "given adequate diversification, gains (….) will offset losses (…). Thus, the net risk turns out to be nil." It is this conclusion that would go on to revolutionise investment theory nearly 20 years later. The person perhaps primarily responsible for this revolution, Henry Markowitz, would in his Nobel acceptance speech in 1990 conclude that "the basic principles of portfolio theory came to me one day while I was reading John Burr Williams *The Theory of Investment Value*." (Markowitz, 1990)

1.2 From investment to (modern) portfolio theory

Markowitz's noticed that the logical conclusion from Williams' investment theory was that portfolio return maximisation would be achieved, under the dividend discount model, by investing in only one security – namely the security with the expected highest return. Such a strategy however flies clearly and squarely in the face of a rational investor facing uncertainty. Instead, investors should be concerned with the return and risk of the portfolio as a whole, considering the variance and covariance of the individual securities in a portfolio. This would imply some level of diversification in order to reduce such covariance. Channelling his inner Shakespeare (Shakespeare, n.d.), Markowitz with this insight launched what is today known as modern portfolio theory, elevating investment theory from individual security analysis to portfolio management.

In his work "Portfolio Selection: Efficient Diversification of Investments" (Markowitz, 1952), Markowitz develops a mathematical relationship between risk and returns, showing that the expected return of a portfolio is the weighted average of the expected return for each security.

Volatility risk (standard deviation) sums to less than its weighted average if the correlation between securities is less than absolute. Markowitz goes on to argue that portfolio that maximise return while minimising risk sit on the efficient frontier.

Building on this theory, James Tobin – he of the recently re-popularised 'Tobin Tax' – built on the work of Markowitz by coining the concept of the 'super-efficient portfolio' – the portfolio everyone should hold in combination with a risk-free asset (e.g. cash) (Tobin, 1958). The risk-averseness of the investor would then determine the ratio between the risk-free and super-efficient portfolio. His theory is also known as the 'separation theorem'. Tobin thus took the intellectual leap from investment to portfolio theory to the dawn of modern asset allocation, the fountain of wealth for investment consultants around the world.

To appreciate the dynamite contained in these ideas, it is critical to marry them with a parallel strand of thinking popularised at around the same time, and finding its origin in an obscure and – save for a coincidence – lost PhD thesis from the turn of the century. Bachelier (Bachelier, 1900), in an analysis of French stock and options markets discovered that "past, present, and even discounted future events are reflected in market prices, but often show no apparent relation to price changes (…). The determination of these fluctuations depends on an infinite number of factors: it is, therefore, impossible to aspire to mathematical prediction of it. Contradictory opinions concerning these changes diverge so much that at the same instant buyers believe in a price increase and sellers in a price decrease." These random price movements became to be known as 'random walk' (or somewhat more irreverently as drunkard's walk, which says something perhaps about the economist profession as a whole).

The random walk literature gave rise to the Efficient Market Hypothesis, which concluded that market prices integrated all available public information about any individual security and thus it was impossible to systematically 'beat the market' as an investor, except by luck, circumstance, insider knowledge, fraud, or some combination of the above. The first formal argument for this idea can be found in Samuelson (1965), who showed that studying historical prices for forecasts is an exercise "doomed for failure [as] the market has already discounted all knowable future information." It is relevant to here to note that Samuelson did not conclude that the market prices were not always correct, but rather superior estimates to alternatives.

This is a critical point in the often maligned efficient market hypothesis (EMH) as it would come to be known. The theory does not suggest by default that markets price assets correctly.

Rather, the wisdom of the crowds is on average superior to the wisdom of any individual investor, that any individual investor would find him- or herself at least half the time (indeed, almost by design) under-performing the market and the other half over-performing. Today, the 'efficient market hypothesis' is most popularly associated with Fama, who in his paper on the behaviour of stock market prices coined the term, defining it as "a market where, given the available information, actual prices at every point in time represent very good estimates of intrinsic value." (Fama, 1965)

The following discussion on the efficient market hypothesis draws from previous publication from the author (Thomä and Chenet, 2016).

The EMH rests on the notion that "a market in which prices always 'fully reflect' available information is called efficient" (Fama, 1970). In such a scenario, information is fully available to all market participants equally and integrated into price formation instantly (ibid.). Crucially, Fama does not eliminate the role of value investing, as originally envisioned by Graham and Dodd, instead suggesting that "If there are enough superior analysts, their existence will be sufficient to insure that actual market prices are, on the basis of all available information, best estimates of intrinsic values."

Economist Michael Jensen argues that (Jensen, 1972), "there is no other proposition in economics which has more empirical support than the EMH." The extent to which this empirical support indeed supports the EMH is critical: "First, investors care about whether various trading strategies can earn excess returns (i.e., "beat the market"). Second, if stock prices accurately reflect all information, new investment capital goes to its highest-valued use" (Jones and Netter, 1993). In order for the efficient market hypothesis to exist, two conditions are crucial. Firstly, as highlighted above, prices need to fully (and equitably) reflect available information, allowing market participants to distinguish between different investments. Second, market participants need to operate as rational, utility-maximising agents, an assumption also known as the "rational choice theory".

The idea of the self-interested, utility-maximising individual entered the economic discourse with the early Classical economists. Notable among them is Adam Smith (Smith, 1776) , who coined the famous adage that "it is not from the benevolence of the butcher, the brewer, or the baker that we expect our dinner, but from their regard to their own interest." In the 19th century, John Stuart Mill (Mill, 1844) then linked this self-interest to utility and rationality, arguing that political economy “concerned with [man] solely as a being who desires to possess wealth, and who is capable of judging the comparative efficacy of means for obtaining that end.” The concept of rational, utility-maximising entered todays discourse, on the shoulders of Walras, Pareto, Jevons, and others, in the form of the Rational Choice Theory, pioneered at the London School of Economics (Robbins, 1938). At the heart of the rational choice theory is the “homo oeconomicus”, the economic man.

Today, the efficient market hypothesis forms a core tenet of finance, both as it is taught at universities (Krugman, 2009) and increasingly thought of in practice. The growth of passive investing (PWC 2014) is arguably a function of the growing consensus that market actors cannot beat the market, given its ‘random walk’ characteristics. Modern portfolio theory, as developed by Markowitz (1952), Tobin (1958), Sharpe (1964) and others relies on the assumption that optimal investing strategies involve adopting market assumptions around prices and diversifying portfolios accordingly.

At the same time, a growing literature is starting to challenge the efficient market hypothesis, suggesting the presence of a number of ‘market failures’ that market actors can exploit and that may lead to the mispricing of financial risk. Market failures represent “the failure of a more or less idealised system of price-market institutions to sustain ‘desirable’ activities or to stop ‘undesirable’ activities. The desirability of an activity, in turn, is evaluated relative to the solution values of some explicit or implied maximum-welfare problem” (Bator 1958:351).

The combination of the efficient market hypothesis and the vision of the modern portfolio theory launched by Markowitz culminated in the capital asset pricing model of Sharpe (1964), who suggested that Tobin’s super-efficient portfolio was in fact the market portfolio, given that the market provided the best available evidence of prices. In the Capital Asset Pricing Model, popularly abbreviated as CAPM, Sharpe suggests there are two types of risks – systemic risk i.e. market risk (called beta), which all securities contain, and idiosyncratic risk (alpha) i.e. risk specific to an individual security. In other words, when prices of an individual security go up as market prices go down, that is the manifestation of alpha. When an investor buys the super-efficient market portfolio, he or she eliminates all idiosyncratic risk.

The CAPM has a number of relatively strict assumptions and comes with a glaring paradox. Thus, it requires homogenous investors with identical return expectations and investment horizons, no transaction costs or taxes, unlimited liquidity and borrowing and lending at risk-free interest rates, all investors seeking to maximise return and minimise risk and asset returns that are normally distributed. The paradox in turn, known as the Grossman and Stiglitz Paradox (Grossman and Stiglitz, 1980), addresses the inconsistency of assuming both value investors and efficient market prices. It notes that "If competitive equilibrium is defined as a situation in which prices are such that all arbitrage profits are eliminated, is it possible that a competitive economy always be in equilibrium? Clearly not, for then those who arbitrage make (private) return from their (privately) costly activity" (ibid.).

1.3 Introducing factors in the 'market portfolio'

Let us take a breath and take stock. CAPM remains the most dominant theoretical force in portfolio management to this day. Adjusted, abridged, but never abandoned, it continues to inform how the largest institutional investors in the world invest their beneficiaries money. However, it has been challenged and further developed. Most adjustments and further developments of CAPM assume some 'factor' that allows for out-performance above and beyond simply buying the market. Thus, Black et al. (1972) show that "portfolios constructed to have zero covariance with the market had average returns that significantly exceeded the riskless rate which suggests that there is (at least) another factor besides the market that systematically affects the return on securities."

Academics have been making careers out of defining exactly what those factors are, all seeking in one form or another to make money out of risks or returns not properly priced by the market. This further development can be found in the Arbitrage Pricing Theory developed by Ross (1976), who argues there are numerous betas with no limit on factors and that these remain undefined in theory. Arbitrage is the common force that brings 'mispriced' assets back into line and thus allows for above-market returns for those that identify this mispricing.

Or the Intertemporal capital asset pricing model by Merton (Merton, 1973), famous for his associated with the Fisher-Black-Scholes Model which he developed in parallel, who noted that "The assumption of a constant investment opportunity set is not consistent with the facts, sincere the exists at least one element of the opportunity set which is directly observable (…) namely, the interest rate, and it is definitely changing stochastically over time." The idea is that there is more than one beta – market factor – with other factors including for example potential exposure to recession, interest rate, taxes, liquidity, dividend yield. These factors drive potential diversification to commodities for example, that may be negatively correlated with equities, bonds.

The criticism of this larger theoretical edifice, and the CAPM, has its origins in empirics. A range of academics since the 1960s have been able to demonstrate other factors acting as predictors of return, notably low price to earnings ratio (Basu, 1977), low book-to-market ratios(Chan, Jegadeesh and Lakonishok, 1995), leverage (Bhandari, 1988), and short-term price momentum (Jegadeesh and Titman, 1993). Partly as a function of this criticism, the CAPM has seen further developments, notably in the form of the intertemporal capital asset pricing model (Black, 1972) and arbitrage pricing theory (Ross, 1976) .

Fama and French (Fama and French, 1993) developed a 3-factor model (FF3) and then a five factor model (1996) when integrating bonds, that, the authors claim, ultimately unifies these model advances based on the simple idea that CAPM works, albeit with more than just a market factor (2004). There remain a range of fundamental criticisms, notably based on the idea of market inefficiency (Rosenberg, Reid and Lanstein, 1985) notably from the champions of chaos theory arguing against the notion of normal distribution of returns (Mandelbrot, Lapidus and Van Frankenhuysen, 2004) and behavioural economics. Falkenstein (Falkenstein, 2012) for example argues that a missing ‘risk premium’ because of human irrationality makes low-risk stocks a better investment.

There are of course paradigms outside of the modern portfolio theory framework with some niche followers, notably “Chaos Theory” and the literature around fractals that seek to capture the ‘random walk’ characteristics developed by Bachelier (Bachelier, 1900) (the theory is perhaps most popularly associated with Mandelbrot (Mandelbrot, Lapidus and Van Frankenhuysen, 2004)), and more technical challenges around some of the underlying assumptions, notably questions around the normal distribution of risks, popularized in the ‘Black Swan’ literature by Naseem Taleb (Taleb, 2010), an issue which we will return to later.

1.4 Application of modern portfolio theory in practice

Despite these criticisms, modern investing largely remains in line with CAPM and arguably increasingly so. Diversification in line with the market is a growing trend, with passive index products that claim to mirror the ‘market portfolio’ on the rise.

It is worthwhile to briefly review for listed equity markets how this plays out. Equities constituted an estimated 26% of global financial assets in 2013 ($64 trillion) ((McKinsey Global Institute, 2014). This makes listed equities the second largest type of investible financial asset after non-securitized loans outstanding. Market-capitalization weighted equity indices determine a significant share of investment for the equity asset class. They are designed to capture a large share of the market, while weighting each security based on its market capitalization.

There are four main uses of benchmark indices: passive investing, closet indexing, use by active investors, and as parent indices for thematic indices. Passive investors invest directly in an index. The allocation of their investment is thus entirely determined by the index.

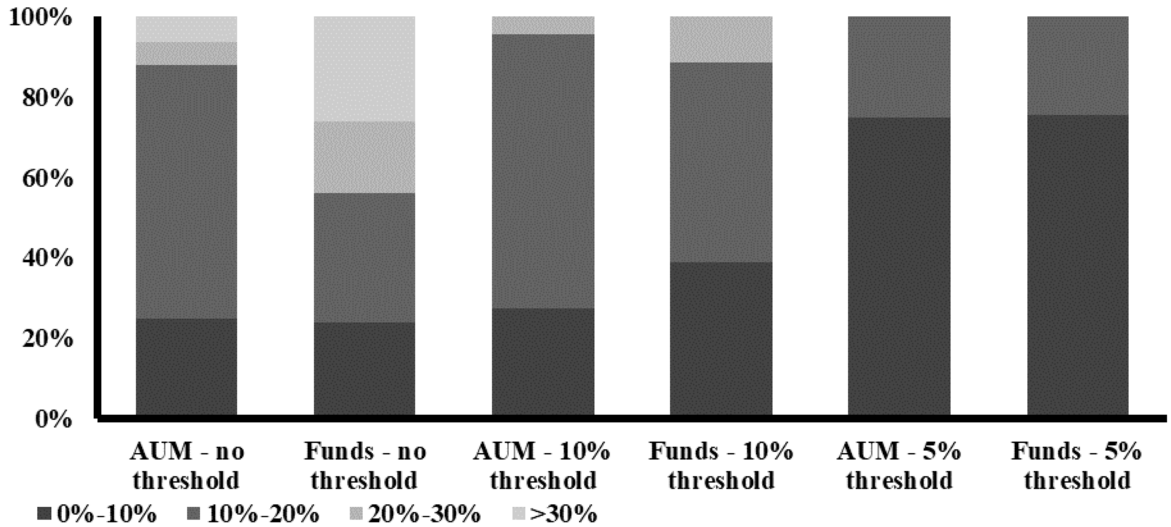
The asset allocation regarding sectors, and by extension technologies, is externally determined. Regarding trends, PriceWaterhouse Coopers (PWC, 2014) predicts passive investments (both for equity and other financial assets) to grow from $7.3 trillion to $22.7 trillion by 2020 (PWC, 2014). In addition to passive investing, there is growing evidence of 'closet indexing'. Closet indexers, as defined by Cremers and Petajisto (Cremers and Petajisto, 2013) can be defined as investors with less than a 60% active share. According to their estimates, the share of 'closet indexers' in US mutual funds has reached roughly 30%.

While the index drives'closet indexers' sector allocation to a large extent, it is unclear to what extent indices influence active investors. In principle, there are two types of uses of indices by active investors – either as sector allocation guidelines and / or as determinants of the 'investable' universe (that being the index). It is in this context that they also appear as performance metrics. The mechanism (in theory) works as follows: Active investors replicate the sector allocation of indices that they are benchmarked against in order to reduce the tracking error with the index (in other words, the divergence in performance).

While the use of indices in this way is widely recognised at a qualitative level, there has been little quantitative analysis as to the prominence of this issue, beyond 'tracking error' figures, which do not directly track this question.

Previous research by the author sought to explore the potential 'closet sector indexing' of active funds using Morningstar and MSCI data (Thomä (a) et al., 2015). Figure 1 presents the results of this analysis for active sector share of assets under management for a sample of non-indexed funds and non-indexed, non-thematic funds (using 10% and 5% as cut-off points). Given that there is no 'golden rule' at what point a fund does not take the sector diversification of the benchmark into account, these two arbitrary cut-off points were chosen to strengthen the analysis. The chart shows that the weighted average active sector share for non-thematic funds in the sample is 7.5%-14.3% (depending on cut-off point) and average active sector share 8.1%-12.6%.

Figure 1 Active sector share of a sample of 185 funds benchmarked to the MSCI World (Thomä (a) et al., 2015)



Thus, the authors (Thomä (a) et al., 2015) find "that the average fund replicated roughly 85%-92% of the sector allocation of the index. Analysis on a smaller sample of funds benchmarked to the S&P500 yielded similar results. The results suggest that indices act as 'hard' sector allocation guidelines for roughly 25% of funds (assuming a 10% thematic threshold) and 'soft' sector allocation guidelines for an additional 68% of funds. It appears likely that a significant share of the funds with little sector diversification are not also closet-indexers."

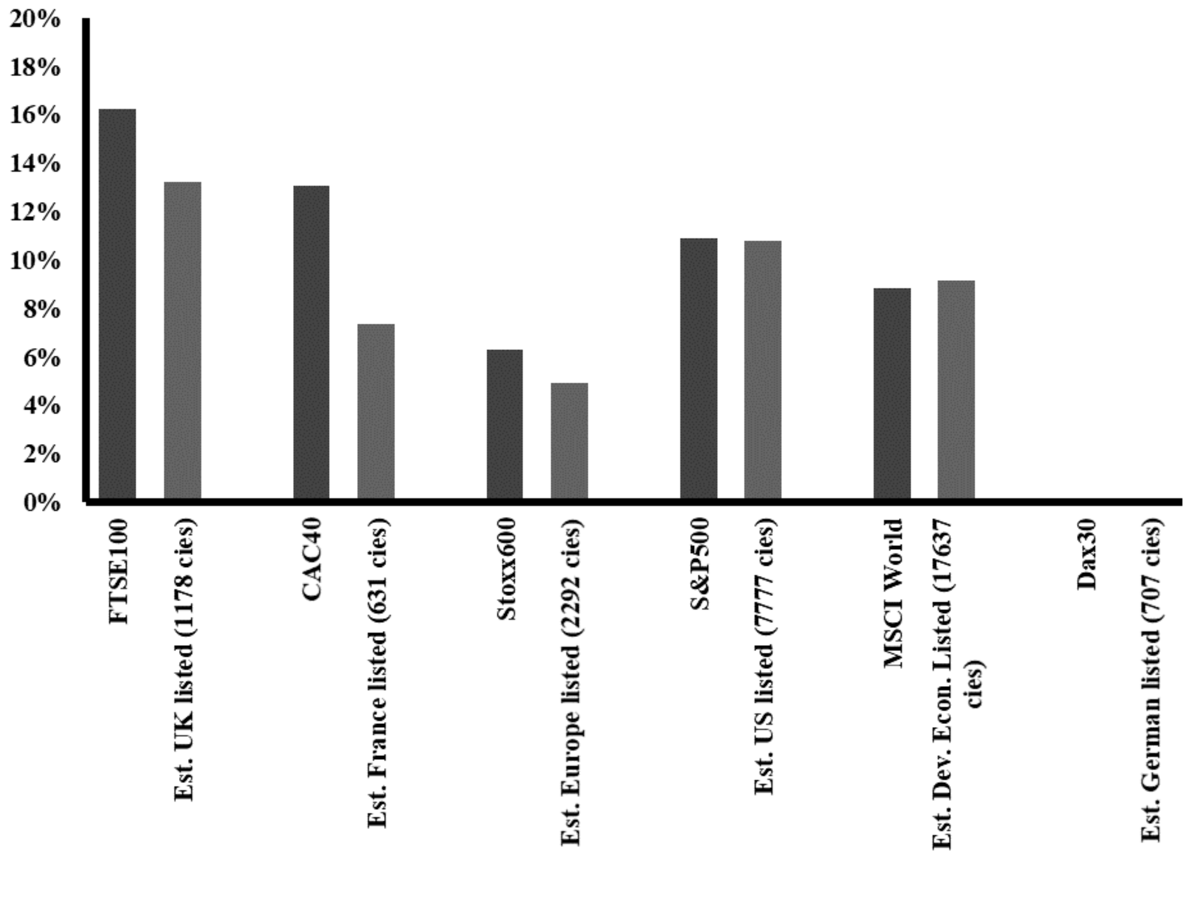
This 'sector-hugging' is driven to a large extent by the notion that indices represent the market in terms of sector weights. In this context then, aligning sector allocation of a portfolio with an index represents a strategy in the spirit of modern portfolio theory around optimal diversification from a sector perspective. The active management share then materializes in terms of stock-picking within a sector. From this perspective, the sector-hugging identified above is both rational and sensible, even for an active manager.

The challenge associated with this premise is the extent to which the underlying assumption – namely that indices reflect the sector weights of the stock market more generally – actually holds.

In theory, given their relative weight in equity markets (usually around 80% or higher), cap-weighted equity indices should not diverge significantly from the listed equity universe they are designed to represent. Indeed, the 'larger' indices more closely represent the listed equity universe.

When looking at the oil & gas sector however, the FTSE100 and CAC40 demonstrate significant divergence, by 3% for the FTSE100 and 5.71% for the CAC40 (Figure 2).

Figure 2 Share of oil & gas in index versus listed equity universe (Thomä (a) et al., 2015)

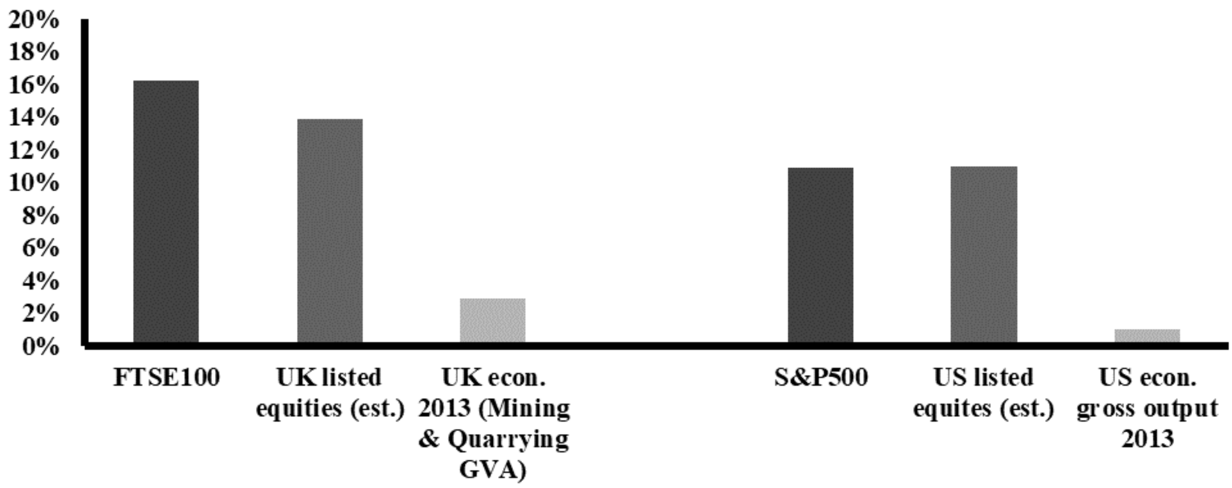


A 3% divergence may not appear large at first sight, however, it is important to put this into context. Based on this 'active sector share', the CAC40 would in the sample analysed in the previous chapter, appear in the top 15% of active funds – assuming the French listed equity universe were the benchmark. Similarly, the FTSE100 would appear in the top 30%. All other indices under review exhibited significantly lower divergence – with the STOXX 600 even slightly under-weighting fossil fuels. Caveats to this analysis is that the stock prices some of the divergence can be explained by fluctuations in stock prices that will be corrected when the index gets recalculated – divergences of 1% or less can thus easily be ‘blamed’ on these fluctuations.

From an energy transition perspective, it is not only the sector, but also the energy technology that matters. Thus, the potential alignment of an index with the equity market by itself does not inform on adequate or optimal diversification. For the oil and gas sector, key questions in this regard relate to the exposure to low-cost / high-cost projects, the breakdown of high-cost projects by energy technology, and the potential climate impact associated with these different technologies. This will be explored further later.

The benchmarks used so far to analyse the diversification of cap-weighted equity indices at sector level related to the listed equity universe. Comparing equity indices to the real economy, important to note, is not a fair comparison – they are not built to mirror the real economy. Nevertheless, it is a helpful exercise when thinking about diversification. To demonstrate the relationship between the equity index and the economy, Thomä et al. (2015) looks at the share of the oil & gas sector in the United States and the United Kingdom, the only two ‘national’ geographies that have significant ‘domestic’ upstream oil & gas exploration and production. Figure 3 demonstrates the disconnect between these two metrics.

Figure 3 Index diversification compared to listed equity universe and economy (Thomä (a) et al., 2015)



The previous analysis suggests a diversification bias of cap-weighted equity indices, which are used to represent the 'market portfolio'. While there is some uncertainty about the degree of diversification bias, by default given varying measures of optimal diversification, the analysis shows relatively conclusively the presence of this bias across indices, either at sector or energy-technology level or both. As a result, passive investors and active investors using these indices as sector allocation guidelines expose themselves to unhedged asset-specific risk. The analysis adds to the growing literature on the shortcomings and challenges to index investing, both regarding different types of biases (e.g. geography, size) and new types of risks appearing with the growth of index investing.

1.5 So what does all of this have to do with climate

The thesis could end here. Investors buy the market, at varying degrees of 'precision', the market is efficient, so why worry about aligning portfolios with climate goals. There are two aspects here. One builds on the factor models, suggesting that financial markets may not price financial risks associated with the transition to a low-carbon economy properly. Aligning financial portfolios with climate goals may thus ensure an outperformance relative to the market if and when that transition materialises.

What this thesis will explore is the extent to which this this is in fact a broader restatement of optimal diversification from an economic activity perspective, rather than a 'tilt' seeking to capture a beta. Mispricing, in turn, may also be of interest for financial supervisory authorities seeking to monitor asset price bubbles in financial markets. The other part of the story is a public policy angle. Here, markets correctly price transition risks and thus models to measure the alignment with climate goals inform policymakers about the adequacy of climate policy signals to affect risk and return in capital markets.

2 The climate/transition risk 'factor'

2.1 How the low-carbon transition creates financial risks

This section builds on and references a previous publication of the author (2° Investing Initiative (a), 2015).

The climate policy angle is quickly told. It buys into the idea that the markets are efficient (or at the very least more efficient than anything else), and so market capital allocation decisions inform policymakers about the sufficiency of climate policies. To that end, it is imperative that policymakers have the visibility around the alignment of financial markets with climate goals, not because a misalignment would or should be interpreted as a mispricing of risk, but because it shows that climate policies are in fact too weak. The other side of the story, and perhaps more interesting for financial institutions, is whether a mispricing exists. This question will be at the heart of this chapter.

The first step to assessing this question is understanding how the transition to a low-carbon economy creates financial risks. A range of academic and 'grey' literature has looked at the question of the extent to which climate constraints create limits on the consumption of fossil fuels (Meinshausen et al., 2009) and how this may create financial risks in financial markets ((HSBC, 2012) (2° Investing Initiative (a), 2015) (Carbon Tracker Initiative, 2013) (Caldecott, Derricks and Mitchell, 2016).[1] These risks are usually labelled 'transition risks'.

As highlighted by the 2° Investing Initiative (2° Investing Initiative (a), 2015), these risks may appear at each step of the chain as a function of policies, market changes, legal challenges, and reputational/social impacts. The subsequent discussion builds to a large degree on this work. The subsequent table provides a summary overview of the types of approaches used to quantify transition risks at different levels and examples.

[1] As highlighted (Financial Stability Board, 2017), these risks, so-called 'transition risks', should be distinguished from physical climate risks and legal risks (Minter-Ellison, 2017).

Table 1 Overview of transition risk assessments at different levels of the investment chain, adapted and updated from (2° Investing Initiative (a), 2015)

	TYPE OF APPROACH	DESCRIPTION	EXAMPLES
Physical assets	Asset impairment tests	Comparison of the value of an asset on the current balance sheet with its recoverable/fair value based on different future cash flows scenarios. Impact of climate policies on energy intensive assets, via e.g. scenarios of energy demand//price	Carbon supply cost curves for fossil fuel reserves, developed by the Carbon Tracker Initiative (Carbon Tracker Initiative, 2013).
Physical assets	Shadow pricing	A forecasted price of carbon (e.g. shadow price) can be used to perform an analysis about the financial opportunity of an investment as a function of different scenarios of climate and energy policies.	Carbon shadow pricing employed by the European Investment Bank as part of the project assessment (European Investment Bank, 2013).
Equities	Revenues / Margins	Two prominent indicators that have been assessed relate to the revenues and the margins of companies. Companies can be affected by different market conditions as a function of their business models, cost structure, responsiveness, or development strategies. The impact of different future conditions on the margin structure of a company can thus be modelled.	Kepler-Cheuvreux estimated the potential lost revenues of oil and gas companies from the IEA 2°C scenario (Kepler Cheuvreux, 2014). CO-Firm estimated the potential lost revenues for the utilities sector, factoring in adaptive

			capacity (The CO-Firm, 2018)
	Valuation models	Expected future cash flows (revenues) and net margins can work as inputs to equity valuation models. The most prominent models in this regard relate to discounted cash flow (DCF) models. DCF modelling use representations of the future in the form of different factors (discount rate, project specific variables, economic variables, cost structure of the company, pricing power, etc.).	A number of sell-side analysts have conducted carbon related valuation studies, notably HSBC (HSBC, 2012). Bloomberg offers an online valuation tool for fossil fuel companies (Bloomberg, 2013).
Debt	Corporate credit ratings	Credit rating illustrates the capacity of a company/government to meet its financial obligations, and its likelihood of default. Time horizons for such evaluations usually rank from 1 to 5 years, which appear to be too short to capture main carbon risks factors as of today.	S&P Trucost is currently developing a model to quantify ratings effects on corporate credit associated with transition risk
	Sovereign debt ratings	The evaluation of credit/sovereign risk relies on the same general approach than for companies. But the exercise at country level is more sensitive to long-term issues relative to social, political and economic factors.	No quantified sovereign risk model to date, although some research initiatives have been developed (2° Investing Initiative (a), 2013)

Financial portfolios	Stress-tests	Stress tests are used to model the resilience of a financial portfolio/institution to severe risk scenarios (variable probabilities and intensities). The risk factors can be specific to the institution or prescribed by supervisors, and the type of scenario is coming from either a statistical description of historical shocks, or a combination of hypothetical events. Usually, the impact is measured on capital and liquidity. Sectorial/macro effects of low carbon transition can theoretically be modelled on GDP, inflation, interest rates, and integrated in stress tests as practiced in the banking and insurance industry.	The Green European Foundation has commissioned a study to investigate a potential carbon bubble effect on the EU financial system (Weyzig et al., 2014).
	Strategic allocation	An investor's strategy depends on factors such as risk appetite, time horizon, liability structure, investment objectives, etc. Its strategic asset allocation will thus rely on risk/return expectations for the different types of investable assets, which are a function of a number of economic and political conditions. These can clearly be a function of the different carbon futures and pathways.	Mercer analysed how the strategic asset allocation of a long-term investor can be affected by different climate scenarios and pathways (Mercer, 2015).

It is relevant to walk through the empirical literature around financial risks at each of these levels at least briefly. In the first instance, transition risks arise as a result of the economic viability of physical assets of companies, households, and governments under various decarbonization pathways. Risks to physical assets can appear from the relative costs of operating these assets and the prices in markets. Costs can either appear directly in the operation of the asset or afterwards, for example through post-facto legal, reputational, or politically-incurred changes in market and policy variables. Risks are particularly material for assets with long time horizons. A production/innovation cycle of 3 years (e.g. in the telecommunications sector related to cell phones) allows for a relatively flexible and rapid adaptation. Disruption is particularly damaging to long-term assets that cannot adapt.

Fossil fuel reserves are one type of high-carbon assets with long time horizons and have arguably received the most attention in the debate on stranded assets. The potential impairment of physical assets was built on the concept of carbon budget (Meinshausen et al., 2009). The impairment of these assets can then be defined relatively simply by whether or not they will be 'productive'.

Recent analysis by McGlade & Ekins (McGlade and Ekins, 2015) breaks down the specific implications for oil, gas, and coal reserves by geographic origin. The analysis suggests that 49% of global gas reserves, 33% of global oil reserves, and 82% of global coal reserves will not be burned in a 2°C economy. These averages hide significant geographic differences. Gas and oil reserves in the United States are only marginally affected by the transition. On the other hand, Canada will only be able to burn 26% of its oil reserves unabated. The analysis references constraints by region or country, which may not apply to companies.

The risk to physical assets is at least in part a function of their lifetime. The more limited the capital lock-in, the higher the expected adaptive capacity.

As highlighted by (2° Investing Initiative (a), 2015), "one way to integrate constraints related to the transition to a low-carbon economy is to assess a project investment based on its viability or opportunity under a 'shadow carbon price', assuming that such a price may be implemented at some point in the future. Some companies have started to introduce an internal "shadow price" of carbon in their decision-making process, either at project level or more strategic business planning level.

In 2013, 29 US companies reported to CDP an internal price on carbon in their business planning and investment decisions, varying from $6 to $60 per metric ton (CDP 2013). Public financial institutions, notably the European Investment Bank (EIB), have introduced a shadow carbon price in project assessment. EIB's approach consists of computing the GHG emissions with and without the project under assessment and using a price of carbon to convert this difference of CO_2eq emissions into a monetary cost (positive or negative) over the lifespan of the project. The prices of carbon used by EIB reflect social cost of carbon estimates from the literature. This shadow pricing is independent of the current and projected value of carbon on emission trading schemes such as the EU-ETS, even for projects exposed to risk on carbon markets."

While risks may appear for physical assets, they are ultimately passed through the system, impacting corporate balance sheets and financial asset prices.

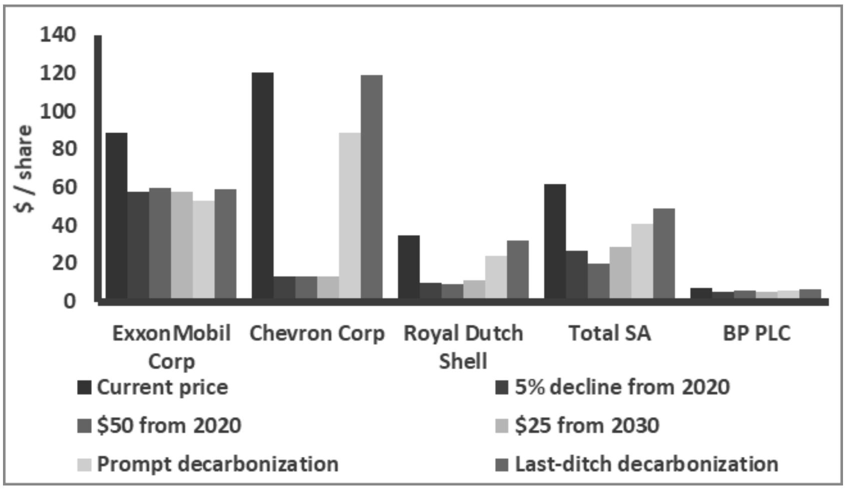
One of the most prominent studies in this field in the past years was led by Mark Lewis at his time at Kepler-Cheuvreux, subsequently joining as a member of the Financial Stability Board Task Force on Climate-Related Financial Disclosures. The analysis covered the oil, gas, and coal sector, specifically the implication in terms of revenues of moving from a 4°C to a 2°C scenario. The net impact of these volume and price effects under the IEA 2°C scenario would be to reduce the revenues of the oil industry by $19.3trn until 2035, those of the gas industry by $4trn, and those of the coal industry by $4.9trn (all in constant 2012 USD) (Kepler Cheuvreux, 2014).

One of the earliest studies in this field is from 2008, conducted by Carbon Trust / McKinsey (Carbon Trust / McKinsey, 2008). The study found that a 2°C scenario could negatively impact companies' valuations could reach up to 35% for oil companies, 44% for pure players in coal mining, and 65% for car manufacturers and aluminium producers. The analysis at the time was limited to sector-level effects and did not specifically quantify effects for individual companies.

HSBC Global Research spearheaded the early valuations work in 2012 and 2013 with a focus on fossil fuels. In 2012, their first piece of research sought to quantify the impact on coal mining companies. Analysing three different carbon futures for the demand for coal, their analysis pointed to potential valuation effects of as much as 44%. In 2013, they published what was one of the first company-specific transition risk analyses explicitly quantifying valuation effects for the oil and gas sector. The results here too were around 40% in terms of negative impact on valuations

In 2013, Bloomberg launched a *Carbon Risk Valuation Tool* (Bloomberg, 2013). The objective of the tool is to quantify the potential impact of various transition scenarios on the earnings and share prices of oil & gas companies, focusing on changes in the price and volume of oil over time. The sample results of the tool can be seen in the figure below, based on analysis conducted in 2013. More recently, the Carbon Tracker announced the launch of a 2°C scenario tool on Bloomberg using asset-level data (Carbon Tracker Initiative, 2018).

Figure 4 The share price under various transition scenarios of major oil and gas companies, as estimated by the Bloomberg Carbon Risk Valuation Tool (Bloomberg, 2013)



One of the more recent research initiatives on this topic is the Energy Transition Risk research project, funded by the EU H2020 research programme, that seeks to develop data, scenarios and models to measure energy transition risk (Et-risk.eu, 2018).[2]

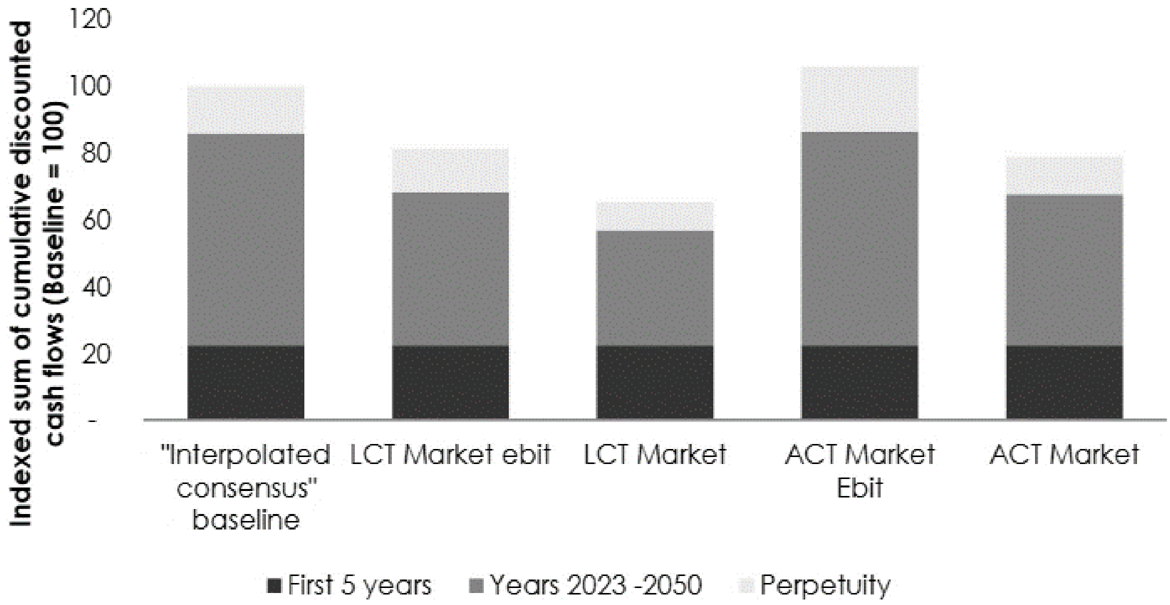
The consortium develops the core tenets of transition risk modelling and discuss some of the key issues. One core idea in this context is the distinction between 'optimal asset pricing' and stress-testing, concepts frequently confused in the discussion of transition risk.[3] This concept is critical for the subsequent discussion of optimal diversification, since the stress-testing concept focuses on ensuring resilience against a tail event, whereas optimal diversification relates more specifically to directly optimizing capital allocation considerations based on the weighted probability of future financial and economic outcomes.

[2] Disclaimer: The author is the research director of the project.

[3] Indeed, this confusion can also be found in prior publications by the author of this thesis (2° Investing Initiative (a), 2015).

The figure below shows some of the quantitative development of the project, related to electric utilities – specifically focusing on Engie (Kepler-Cheuvreux / CO-Firm /, 2017). One key take-away is that under some transition scenarios – notably the ACT scenario (Ambitious Climate Transition scenario), EBIT may actually be positive.

Figure 5 The indexed sum of cumulative discounted cash flows under various scenarios for European utility company Engie (Kepler-Cheuvreux / CO-Firm /, 2017)



The study is also interesting as it presents perhaps the only attempt to seek to quantify whether transition risks are actually already internalized into current asset prices and the potential to transmit this risk through a risk premium. The next section will explore this question further, specifically the question as to where this assumption comes from that these risks are mispriced to begin with and the theoretical evidence underpinning this assumption.

2.2 Theoretical evidence for the mispricing of risk

This section builds on and references a previous publication of the author (Thomä and Chenet, 2016).

"The research around these risks has primarily focused on examining the potential materiality of these types of risks to financial market assets and actors. Less explored in this debate is the question of whether financial market actors are already correctly pricing these risks, challenging the 'bubble' assumption.

Thus, while there is growing consensus that these risks may materialise, it is unclear whether current asset prices already reflect them. While there is academic evidence of a sudden tipping point in climate policies that can create sudden, unexpected transition risks (Aghion, Teytelboym and Zenghelis, 2014), such literature does not directly question how actors may or may not already be pricing probabilities of such 'surprises'.

The question of asset mispricing is key for two objectives. First, it is important from a financial stability perspective, as asset mispricing can lead to asset bubbles that may have systemic effects or at the very least create financial risks for some actors and asset classes. Second, and linked to the first, asset mispricing is also relevant from a policy and social perspective. Asset mispricing can lead to inefficient capital allocation, which in turn may inhibit growth as capital does not go to its best use. In this particular case, this may be even more problematic in so far as such inefficient capital misallocation may exacerbate economic inefficiencies that relate to the mispricing of the social cost of carbon. Thus, mispricing not only inhibits growth but also has an additional negative impact on public welfare more generally, through negative health impacts (Watts, 2015) and other social and political costs.

To understand why markets may misprice transition risks as a particular risk class, it is important to first look at the theoretical literature on market failure, in particular, the tenets highlighted above: notably rational choice theory and normal distribution assumptions.

One of the strongest theoretical criticisms of the utility-maximisation model comes from Herbert Simon (1957), who coined the term "bounded rationality". Simon (1957:198) argues, and it is worth quoting him at length, that "the capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problems whose solution is required for objectively rational behaviour in the real world (…) The first consequence of the principle of bounded rationality is that the intended rationality of an actor requires him to construct a simplified model of the real situation in order to deal with it. He behaves rationally with respect to this model, and such behaviour is not even approximately optimal with respect to the real world." As a result, people use heuristics as opposed to optimisation. Agents do not optimise, but 'satisfice'."[4]

[4] Related to this concept is the idea of "selective rationality", articulated by Comanor and Leibenstein (Comanor and Leibenstein, 1969) in the context of their work on "x-efficiency".

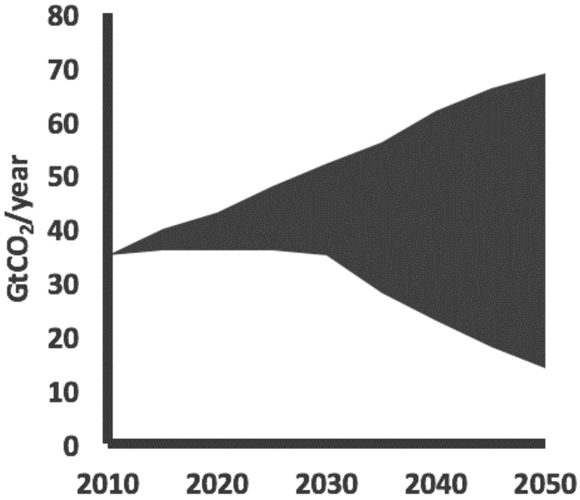
From an agent's perspective, this may be 'optimal'. Equally, from an investment perspective, this means that agents may not realise (or even attempt to realise) maximum returns. In this case, price formation does not reflect all information, given that agents have not attempted to optimise.[5] As a result, prices may become skewed, leading *potentially* to capital misallocation.[6]

The issue of the model is core to the question of transition risks. Transition risks are unlikely to be captured by traditional risk models – models which are equated to be representatives of real-world risks. There are a number of reasons for this, most notably perhaps the breakdown of the normal distribution principle associated with these risks and the lack of historical data (ibid.). As suggested in the figure below, the distribution of transition scenarios is not normal in so far as it exhibits a weight in one direction – there seems to be a visual weight that drags the bottom part of the curve downward. The chart thus suggests a skewed distribution in one direction – in this case in the direction of the probability related to a 2°C decarbonisation pathway. Naturally, this distribution is somewhat 'artificial', perhaps more of a 'social distribution' than a quantified one – the number of 2°C scenario is not necessarily a testament to its probability. Nevertheless, as a proxy for distribution, it shows a skew.

[5] This is not to be confused with agents not integrating all information as a result of costs. Here, allocative efficiency according to the rational actor still exists because the costs associated with the acquisition of information are seen to be higher than the associated benefits. In the scenario presented here however, actors do not integrate all information, even if this is profitable because they do not seek maximum profits. The distinction will be revisited later.

[6] A scenario could be envisioned where agent satisficing has an equal effect on all financial assets and thus not lead to a skewing of prices. While possible, the 'zero error' hypothesis seems unlikely given that there is no good reason why an unconstrained decision-making process should have a distribution with a mean of zero. Such a scenario, while worthy of further research, will not be explored in further detail in this paper.

Figure 6 Range of IPCC scenarios (Thomä and Chenet, 2016)



While the normal distribution assumption is no longer as core to finance as it used to be, it still forms the basis of all core models, including the models introduced by Markowitz (Markowitz, 1990) in the context of modern portfolio theory, Arrow-Debreu models (Arrow and Debreu, 1954)), Black-Scholes Options Pricing Model (Black, 1972), and more recent models of credit risk (see Chatterjee 2012).[7] IMF stress-testing models for example also rely on this assumption (Ong, 2014).

One core reason for using the normal distribution is the additional complexity a non-normal distribution introduces in the models – a complexity potentially avoided at least in part as a result of the bounded rationality principle. Agents satisfice by using simplified assumptions to reduce complexity. This may make sense for an agent that doesn't seek to optimise – and thus be considered rational – but it may create systematic biases in models that lead to a sub-optimal pricing of risks.

The bounded rationality thesis related to the nature of models would thus potentially apply to transition risks. Normal distribution assumptions may systematically bias against the skewed risks related to the transition to a low-carbon economy.

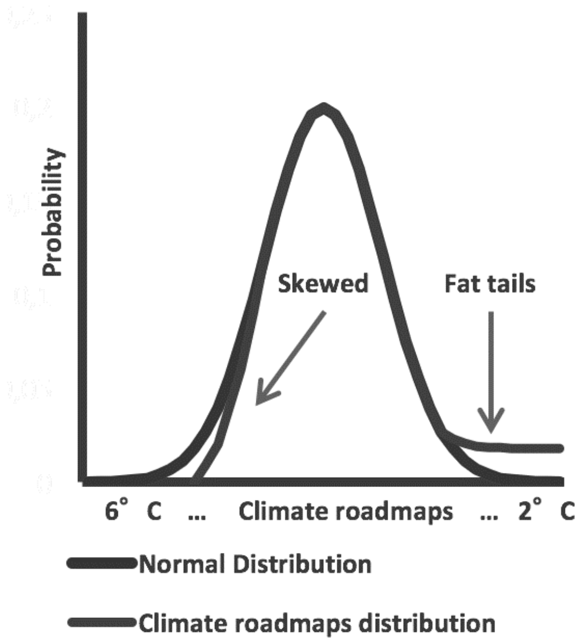
There are other ways agents may not optimise, notably regarding dealing with tail risks. The idea that investors do not deal with risks equitably finds its roots in the Prospect Theory, developed by Kahnemann ((Kahnemann and Tsversky, 1979)) and Fox ((Fox and Tsversky,

[7] Haldane (2012) provides a review of the history of normal distribution in financial market models, from which this paper borrows heavily.

1995)). Fox and Tsversky argue that investors appear risk-averse for small losses, but indifferent to, or at the very least less impacted by large losses. In other words, the level of risk aversion is at least partly a function of the size of the loss, where investors are willing to take larger bets with a higher risk of loss. More recently this literature has been popularised in its application to models by Naseem Taleb (Taleb, 2010) and his work on tail risks, which he describes as 'black swans' or 'fat tails'. Taleb (ibid.) highlights the extent to which financial market models under-weight probabilities at the tail end of the distribution.

As outlined above, the skewed nature of climate roadmaps suggests risks associated with this transition are not normally distributed. Another way the risks are not normally distributed is potentially their characteristic as involving 'fat tails'. While 2°C outcome may be unlikely (Pidcock, 2012), it remains the global policy commitment. The extreme end of the tail may thus be more likely than in a normal distribution – where the probability of an event outside two standard deviations is about 5%. While possible and perhaps probable, it is not clear whether transition risks will indeed have fat tails. The figure below visualises the joint impact of skew and fat tails on a distribution function.

Figure 7 Illustrative example of the normal and climate roadmap distribution (Thomä and Chenet, 2016)



At the same time, what does appear apparent is that the 2°C event may be extreme. It is on the lower end of the spectrum of climate roadmaps and far removed from the current business as usual – defined for example by the International Energy Agency as the "Current Policy Scenario" associated with roughly 6°C global warming (International Energy Agency (a), 2016). What is thus possible is that financial markets collectively are willing to take risks associated with the 2°C transition in the vein of Prospect Theory (Kahnemann and Tsversky, 1979). In other words, even if the probability of the tail event is not over-stated, its ramifications in models is under-stated as a result of the cognitive bias of market actors vis-à-vis these tail risks.

The discussion here in a way pre-empts the subsequent discussion in the next section on cognitive biases related to market actors' *actions*, beyond models. It also has a place here, however, insofar as financial market models may reflect this bias in two ways. First, inputs chosen in the analysis, e.g. the scenarios around cash flows. tend to congregate around the mean or median assumption, in particular when it comes to climate transition questions.[8] Second, the emphasis on single indicator outputs for example in discounted cash flow models highlights mean results without creating transparency around potential tail risks.

Appropriate at this stage then is the reference to a strand of literature that, while having its origin in the traditional classical and neoclassical economics, has been picked up by the market failure literature as well. This relates to the distinction between risk and uncertainty, a distinction first introduced in the economic debate by Frank Knight in 1921 and then further developed by Keynes in the General Theory ((Keynes, 1936)).[9] According to Knight (Knight, 1921), "risk means in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of this character (…) It will appear that a measurable uncertainty, or 'risk' proper, as we shall use the term, is so far different from an *unmeasurable* (sic!) one that it is not in effect an uncertainty at all. We shall accordingly restrict the term 'uncertainty' to cases of the non-quantitative type." This definition is largely uncontested.

The idea of risk and uncertainty was particularly made relevant in the context of the financial sector by Minsky (Minsky, 1999), who argued that the inability to quantify all future risk scenarios was one of the factors that led to financial crises. Simon (Simon, 1957) argued that uncertainty, unlike risk, implies that contingencies cannot be assigned probability distributions

[8] These assumptions may be more diverse in the case of economic stress-tests now part of the standard toolbox of regulators.

[9] Knight arguably holds the economists crown for under-statement, in particular in hindsight, by beginning the book with the line: "There is little that is fundamentally new in this book." (Knight, 1921)

and hence cannot be fully insured against. This is particularly the case in future-oriented decisions such as investment. Thus economic agents might fall back on rules-of-thumb. The key idea then is that, in the presence of both risk and uncertainty, investors may not be able to make optimal decisions.

Transition risk is likely to be particularly subject to this constraint. As outlined above, climate change models and associated roadmaps are highly complex and subject to a wide range of assumptions. Data to input models are not necessarily available or available at affordable costs to investors. Already quantifying the possibilities associated with each degree of warming is a particular challenge, which is also why the 'fat tail' assumption cannot be validated at this stage. In addition, even if these probabilities could be quantified, each degree of warming is associated with a range of different technological roadmaps, some emphasising one technology over another. There are over a 100 different roadmaps (Caldecott, Tilbury and Carey, 2014). For example, given the potential deployment of carbon capture and storage, a range of different fossil fuel production volumes can be linked to a specific climate outcome. All of these, of course, pre-supposes capacity to assess and quantify these challenges, which the bounded rationality literature suggests is lacking. There is no reason to believe climate literacy is particularly high among financial sector actors. This is a result of the fact that climate change related risks do not involve a historical precedent at a sufficient scale – and thus relevant historical data - that would have formed part of the education of individuals working in financial markets.

There are two key characteristics of the market failure literature on economic agents relevant from a transition risk perspective that fall outside the scope of models, namely the role of time-inconsistent preferences and the role of institutions. Each of these aspects will be discussed in turn and linked to the analysis of the expected characteristics of transition risks.

One of the main tenets of the rational choice theory in terms of utility-maximisation is the time-consistency of preferences by economic agents, in other words a "no regret" position at point t+1 relative to their choices at point t.[10] If this were not the case, utility would not be maximised inter-temporally. Mathematically, this is the equivalent of an individuals having an exponential

[10] Of course, rational choice theory does does not assume we do not regret our decisions given 20/20 hindsight. Rather, it assumes that we do not disagree with our 'former' self's decision, given the information set available at the time the decision was made.

discount function, implying that we (as in humans) discount the future at a steady rate.[11] Most economic modelling and analysis relies on the premise that "we do not suppose time to be allowed for any alteration in the character or tastes of the man himself." (Marshall, 2009) Paul Samuelson adds that "what is assumed is that consumers are fairly consistent in their tastes and actions – that they do not flail around in unpredictable ways, making themselves miserable by persistent errors of judgement or arithmetic." (Samuelson, 1937)

As crucial as this condition for the theory of utility-maximising agents, as weak is its theoretical and empirical foundation. In practice, the discounting by economic agents usually resembles hyperbolic discount function (Laibson, 1997) (Thaler, 1981).[12] The hyperbolic discount function suggests economic agents have 'present-biased preferences', discounting the immediate future and then the long-term future progressively at a lower rate.

This is important because it suggests that investors may not optimise inter-temporal returns.[13] In the case of transition risks, inter-temporal inconsistency is particularly important because transition risks are likely to be long-term and thus heavily discounted over the short-term. Transition risks may thus be mispriced in the context of hyperbolic discount functions not because investors do not *believe* the risks will materialise, but discount their financial impact. In the same vein, from a broader capital allocation perspective, this may also suggest more long-term payoffs from 'climate-friendly' investments may similarly be discounted. Discounting is obviously visible in financial risk models as well, although here the issue is probably rather the practice of extrapolating current trends rather than the discounting.

Beyond models, however, hyperbolic discount functions lead economic agents to ignore long-term trends. Thus even where models can integrate long-term risks, these are not considered by the economic agent because the actors themselves discount the cash flows associated with these

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[11] While the discussion here focuses on the market failure associated with time-inconsistency in terms of allocative efficiency, the same problem obviously persists for policy, where it is more frequently labelled the dynamic-inconsistency problem (Kydland and Prescott, 1977).

[12] While the hyperbolic discount function has achieved popularity with the rise of behavioural economics, the notion of time-inconsistent preferences is obviously not new and can be, at least in the field of economics, traced back to Smith and Hume (Palacios-Huerta, 2003).

[13] Hyperbolic discount functions may be rational from an individual's perspective. If long-term paybacks are more uncertain, for example due to trust issues or external uncertainties, it may be rational to prefer a short-term payoff. Uncertainty may also exist about the ability to capture that payoff, particularly in finance. Equally, uncertainty is only one factor in explaining the hyperbolic discount function. Moreover, uncertainty isn't an exogenous variable, but will be a function of a range of endogenous factors.

events. By extension, there is no incentive to engage in an exercise beyond extrapolation given that potential hits to long-term cash flows are not material to the economic agent.

This issue is particularly relevant for climate change and transition risks, something worth highlighting in further detail at this stage. The particular policy challenge of integrating long-term climate costs into short-term policymaking is one that goes beyond financial markets (Slawinski et al., 2016). The link to finance was made explicitly and prominently by the Governor of the Bank of England in a speech at Lloyds of London that arguably initiated to a large degree subsequent supervisory action, titled “The Tragedy of the Horizons” (Carney, 2015). This work has triggered research initiatives by organisations like FCLT (Focusing Capital on the Long-Term (FCLT), 2015) and the 2° Investing Initiative (2° Investing Initiative (a), 2017)

There may be another reason long-term risks are not integrated, which relates to externalities and principal-agent problems. The discussion on market failures has thus far focused on whether agents are rational and maximise their utility. It is important also to address the other part of the equation highlighted at the beginning, namely the extent to which financial markets are informationally efficient, independent of the rational nature of actors. This other side of the literature focuses on questions of market design creating inefficiencies, notably through transaction costs, agency costs in the context of the principal-agent problem and asymmetric information, and externalities.[14]

Principal-agent problems describe a situation where both the incentives and the information of a principal (for example an owner of assets or a voter) and the agent (the asset manager or politician respectively) are not aligned.[15] The differences in incentives and interests for the two parties are likely to be a frequent if not omnipresent characteristic of these types of transactions. They become problematic in the context of asymmetric information, allowing the agent to

[14] A range of other factors have been purposefully excluded in this debate, notably the presence of incomplete markets (Magill 1996), the literature on transaction costs (Coase, 1937) (Dahlmann, 1979), and the role of power in determining prices (Bowles, 1985). While other factors may also play a role, the discussion is limited to these factors that seem immediately material for the questions around transition risk. Other factors may prove to be equally material over time, where excluded however at this point given the lack of immediately obvious link.

[15] The term “Principal” and “Agent” have their origin in law, where it refers to two parties of a contractual agreement.

capitalise on superior information to the principal.[16] The associated costs of this information asymmetry are so-called "agency costs" (Jensen and Meckling, 1976)

Externalities, in turn, are "the cost or benefit that affects a party who did not choose to incur that cost or benefit" (Buchanan and Stubblebine, 1962). The presence of externalities will lead to prices that are sub-optimal as they do not integrate the full range of cost and benefits associated with an asset (Greenwald and Stiglitz, 1986).

The externalities associated with climate and the environment are usually referred to as the "tragedy of the commons", after a seminal essay of the same name published by Garret Hardin in 1968 (Hardin, 1968). Interestingly, the analysis of externalities usually does not distinguish between inter-temporal externalities, where the affected party is somebody in the future and geographic externalities, where the affected party is in the same geography (analytically speaking). In terms of climate change, the question of externality has usually focused on the extent to which the costs of climate change are externalised by those who are responsible for it (Stern, 2008).

Costs associated with climate change are socialised across the economy and will likely in some way impact all economic actors negatively, more or less.[17] Costs associated with the transition to a low-carbon economy will be more focused, however. These types of costs are likely to impact only a few sectors, industries, or even just a select number of companies within industries. Similar to physical risks, these costs can also be externalised.

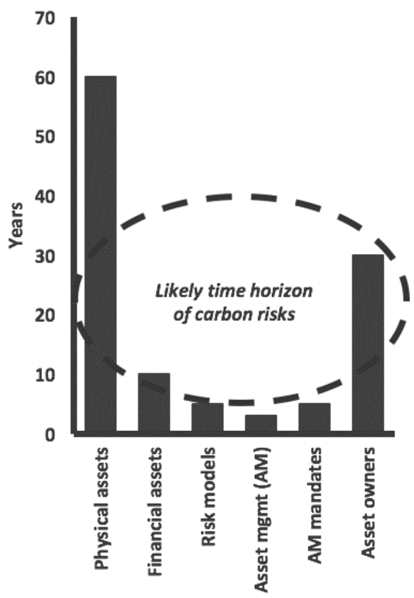
In financial markets, this may be the case in the presence of principal-agent problems. In such a scenario, short-term asset managers externalise long-term costs associated with their investments to asset owners. The challenges around measuring long-term performance and risk of asset managers allows them to do this (World Economic Forum (WEF), 2012). Asset managers may thus, even if financial models reveal long-term risks, ignore this risk as it not with them, but with asset owners over the long-run. Taking these risks then allows for some potential short-term benefit. Part of this externalisation happens in the models and use of data and thus can relates to the first part of the discussion above. Even when these models are

[16] The concept of information asymmetry has been developed most prominently by Akerlof (Akerlof, 1970), who won the 2001 Nobel Prize in Economics for his work in this field.

[17] That is not to say all economic actors will face the same costs, nor that all geographies will be affected the same. Rather, that some economy-wide costs at global scale and across most countries will affect most actors in some way.

adjusted, however, it does not respond to the principal-agent, externality, and time-inconsistency problem, the reason the discussion here focuses on the economic agent rather than the model itself.

Figure 8 Illustrative time horizons across the investment chain (2° Investing Initiative (a), 2015)



Beyond time horizons, institutions can also play a role for transition risk assessment in financial markets. The individual's rational, utility-maximizing behaviour marginalizes the role of institutions in these frameworks.[18] The most obvious evidence for this lies in the fact that the actual preferences determining utility are exogenous variables in neoclassical models (Savage, 1954). According to North (North, 1993), "history demonstrates that ideas, ideologies, myths, dogmas, and prejudices matter. (…) [Institutions] are made up of formal constraints (e.g., rules, laws, constitutions), and informal constraints (e.g., norms of behaviour, conventions, self-imposed codes of conduct), and their enforcement characteristics)". Hence, the idea of an embedded economy: the economy functions in a specific social-historical context.

To the extent that rational choice theory acknowledges this, it argues that rational individuals in the context of competitive markets ensure the formation of efficient institutions (i.e. minimizing transaction cost, maximising utility), including incidentally cultural institutions.[19]

[18] Institutions in this study are understood in the political economy tradition (North, 1993)

[19] The origin of this analysis is with Coase (Coase, 1960), who applied this logic to law, where modern common law is frequently said to be driven by economic 'efficiency' considerations, as opposed to 'natural rights' considerations.

This ignores a range of behavioural elements, however, notably path-dependency, where existing economic institutions are the contingent result of particular historical developments and therefore have no a priori claim to optimality or efficiency. Perhaps the most famous example in this regard is the QWERTY-keyboard, said to have been established for optimal typewriter typing (to avoid bunching of keys), but no longer be optimal for computers (David, 1985).[20] This is known as 'evolutionary economics' (Nelson and Winter, 1982).

One important aspect to highlight in this regard is that institutions can create decision-making parameters that are 'rational' for the individual, but where the rationality is specific to the institutional context. For example, it is rational for asset managers to maximise short-term value given the institution of short-term remuneration to which that asset manager is subjected. It would naturally be irrational from a profit-maximisation perspective to do the same if their remuneration is a function of more long-term performance and value.

The 'atomism' of the rational choice theory falls short in other respects as well, beyond a discussion of institutions. The key here is that individuals in a group face a different utility function (and a different desire to satisfy that utility function) relative to being in isolation. Bikhchandani (Bikhchandani and Sharma, 2000) for example argues that herding behaviour partly explains booms and busts, where market participants exhibit 'irrational exuberance' and move as a crowd into a sector, overvalue their prices and ultimately move out, leading to a crash.[21] It is better to be wrong in a group (Brennan, 2008).[22]

While it is difficult to find evidence on herding behaviour related to climate change, there is evidence that the transition to a low-carbon economy, despite success in recent years, is not fully on the radar screen of investors. The NGO Asset Owner Disclosure Project (AODP) finds that about half of all surveyed asset owners have a 'no score' on climate change issues and

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[20] It is an open question as to whether other keyboards would be more optimal in terms of typing on a computer. In any event, however, the legacy of the QWERTY-keyboard, having established its pre-dominance largely independent of efficiency considerations, cannot be denied.

[21] Keynes (Keynes, 1936) famously called the financial markets 'a beauty contest'.

[22] Much of the literature here is inspired by Mackay (Mackay, 1841)

another 35% score a D.[23] At the same time, other surveys (Mercer, 2013), (Novethic, 2015) do identify action on climate change. The evidence is thus not unequivocal.

In conclusion, it should be noted that the distinction between these two categories (i.e. models and economic agents) is questionable, given the overlap and interplay between the two factors. At the same time, the key takeaway from the review of the theoretical literature relates to the fact that transition risk assessment challenges is not confined to the models. In other words, there is a case to be made that there is a mis-assessment of transition risks in financial markets and that this mis-assessment relates at least in part to the institutions around risk-assessment. This suggests that solving this challenge requires not only better, smarter risk models, but in equal measure addressing key features of market design – notably the principal-agent problem and externalities - and potential 'irrationality' of market actors – notably their time-inconsistent preferences." (Thomä and Chenet, 2016)

2.3 Where does this leave modern portfolio theory?

The discussion in this chapter did not prove that there is a mispricing. Indeed, it did not seek to prove that there is a mispricing, nor is it clear that such mispricing – should it exist – would even be consistent regarding its manifestation. Instead, it sought to demonstrate that the risks associated with the transition to a low-carbon economy – transition risks – may not be properly priced and theoretical evidence suggests that this may be likely. This thesis proposes one potential response in the subsequent chapters to this challenge in terms of restating modern portfolio's interpretation of optimal diversification.

Crucially, the theoretical discourse presented in this chapter provides two angles under which measurements around alignment of financial portfolios operates. One is a more holistic interpretation of the market portfolio representing the 'market belief' about the future outcome regarding transition pathways. Institutional investors seeking to take an alternative view to this outcome then need a basis to benchmark the transition outcome of their portfolio management strategy with climate goals. A more holistic interpretation of the 'market portfolio' then considers the market portfolio as contingent on the investor belief regarding climate outcomes.

An alternative angle is that the 'market portfolio' actually is contingent on the critical assumption of homogenous investors. Once this assumption is softened, either because

[23] The AODP ranks based on credit ratings from AAA to D and an "X" for when no evidence / response was identified (Aodproject.net, 2018).

investors may not all be utility maximizing, or operate with different investment time horizons and associated discount rates, different investors will have different market portfolios even if they all share the same beliefs about future cash flows. This is then simply a result of discounting these cash flows differently.

3. From finance to climate goals

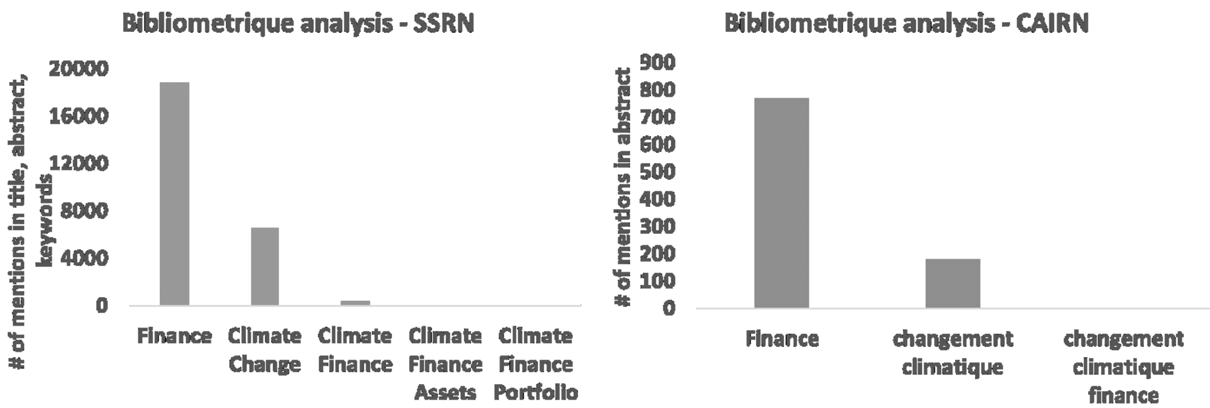
3.1 Overview

As outlined in the previous section, to date no metrics have ever sought to measure and benchmark what 'optimal diversification' or the market portfolio implied under one or the other transition scenario. Developing such an indicator requires as a starting point a translation and analysis connecting climate goals and finance.

The finance sector and climate change are linked via two channels that involve a number of different intermediate steps (2° Investing Initiative, UNEP-Fi, WRI, 2015). The first channel involves the impact of climate change and climate change mitigation on financial asset prices in financial markets. The second channel involves the impact of investment and financing decisions in financial markets on the real economy and by extension GHG emissions and climate change mitigation.

At first glance, these two issues seem somewhat disconnected. Climate change is a planetary phenomenon. Finance relates to the intermediation of capital in the financial and real economy. A bibliometric analysis conducted at the start of the thesis reflects this analysis (Figure 9).

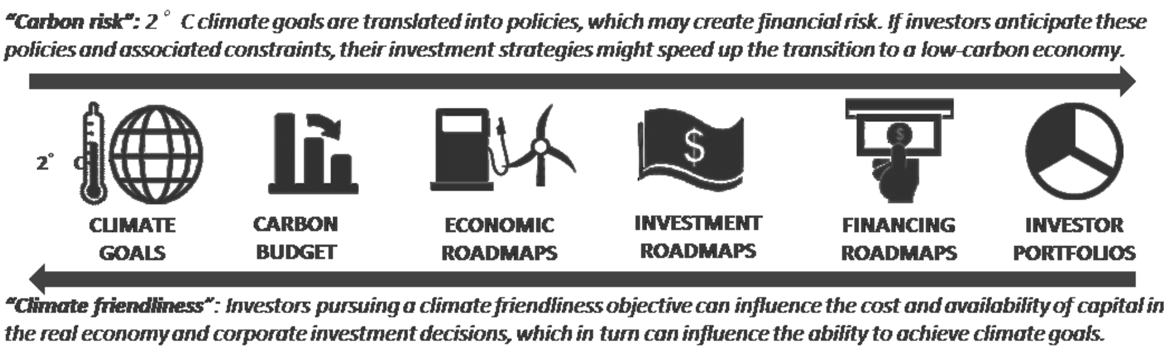
Figure 9 A bibliometric analysis of the literature on finance and climate change



In practice, however, a chain of connected market, policy, and technology drivers are creating an interface between these two worlds. This chain starts at the societal objective and political mandate defined in Paris at COP21 in 2015 to limit global warming to well below 2°C, with a target of 1.5°C (UNFCCC, 2015). This global target requires a curb on anthropogenic GHG emissions, which according to best available evidence and the overwhelming consensus of scientists is responsible for the current spike global warming seen in a range of scientific data and will continue to contribute to global warming if not curbed. GHG emissions are in turn associated with a range of economic activities and sectors that permeate almost if not all economic activity – power, transport, industry, real estate. All of these sectors need to eventually reach – on balance – net zero GHG emissions to stabilise global warming.

Shifting this economic activity to 'net zero' in turn requires a change in investment levels of companies, households and governments, investments of course which are at least in part intermediated and financed in many cases by capital markets and the financial sector more generally. This then completes the circle from climate change to financial markets – and back. The image below summarises this link.

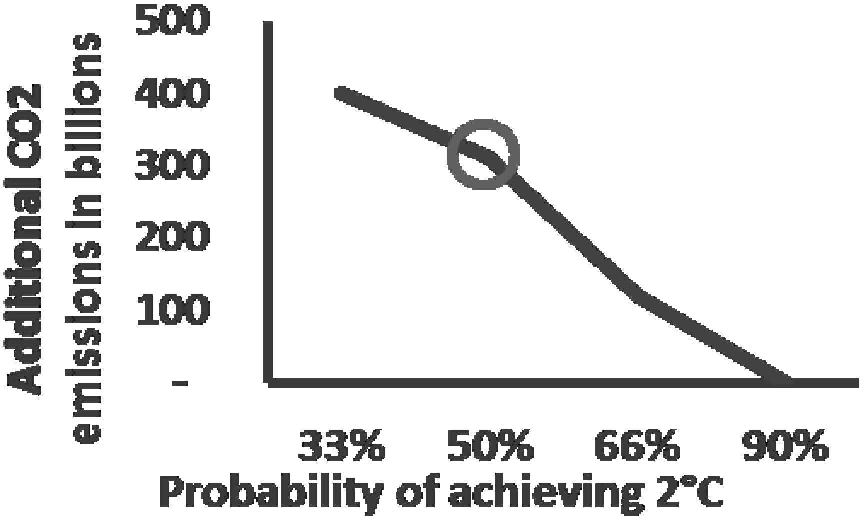
Figure 10 The link between climate goals and investor portfolios (2° Investing Initiative, UNEP-Fi, WRI, 2015)



2.4 From climate goals to carbon budgets

Climate impacts arise as a result of anthropogenic GHG-emissions. Scientific research has linked the 2°C climate goals to certain levels of GHG in the atmosphere and the probabilities that, given certain levels of GHG-emissions, average global temperature increases can indeed be limited to 2° C. Meinshausen et al. estimated that a 2000-2049 budget of total CO2 emissions of 1437 GtCO2 corresponds to an "illustrative" probability of 50% to exceed 2°C in the 21st century (Meinshausen et al., 2009). The objective responds to a growing body of evidence that global warming above 2°C relative to pre-industrial levels will cause significant damage to the planetary ecosystem, human welfare, as well as economic growth. While the purpose of this thesis at its heart is to explore how this objective translates into targets and implications for financial institutions, it does not seek to relitigate the debate about the anthropogenic influence and on the climate and the uncertainty around the impact this will have on the planet. For the further argument, it is not relevant to further analyse this question.

Figure 11 CO2 emissions and the probability of achieving the carbon budget (2° Investing Initiative (a), 2015)



These 'carbon budgets' are then used as the basis of subsequent developments of economic climate roadmaps. Thus, the IEA 2° C scenario (2DS) assumes a CO2 concentration of 440 ppmv by 2100 , with an associated probability of limiting warming to below 2° C in the 21st Century to 80% (International Energy Agency (b), 2016).

A key question associated with carbon budgets relates to the time horizon. Thus, carbon budgets may involve a non-linear trajectory over the next decades. Finally, there is the question of the time by which the global economy will be 'carbon neutral' or even 'carbon negative'. The 'Representative Concentration Pathways' map these different trajectories. In the case of a 2° C scenario, annual GHG-emissions are meant to peak within the next decade and then reach zero by around 2070. These carbon budgets then point the way for the nature of economic roadmaps and scenarios for GHG-emissions by sector, the development of these GHG-emissions, and potential 'off-sets' – for example through Carbon Capture and Storage (CCS).

3.2 From carbon budgets to economic roadmaps

Implementing GHG-emissions targets in practice requires an understanding of the associated energy, industrial, and technology mix that enable GHG reductions. The Oxford Smith School Stranded Assets Research Programme has identified nearly 80 different scenarios that set out the energy-technology roadmaps either at national or international level (Caldecott, Tilbury and Carey, 2014). The scenarios show a wide degree of divergence on the level of granularity (country, sector, company) and time horizons. Only 59% of the scenarios reviewed had original quantitative data.

The most prominent global scenarios are those of the IEA (International Energy Agency (a), 2016), although environmental NGOs & research organisations such as Greenpeace (Greenpeace, 2015) and WWF/Ecofys (WWF, 2011) have developed alternative global scenarios. These usually distinguish themselves by challenging the prominent role that Carbon Capture and Storage (CCS) and nuclear power play in the IEA scenarios, the impact of energy savings, and by emphasizing the relative contribution of shifts in transportation patterns.

For Europe, the European Commission has published an energy-technology roadmap for 2050 (European Commssion, 2012). Similar to other scenarios at international level, the EC roadmap provides two trend scenarios (Reference scenarios and Current Policy initiatives scenarios, updated for changes in policies following Fukushima) and five 'decarbonisation scenarios' (High Energy Efficiency, Diversified supply technologies, High renewable energy sources, delayed CCS, low nuclear). Specific scenarios are also sometimes developed at the country level.

Economic roadmaps are different in terms of their sector coverage, their time horizon, and their geography. As a result, their results also vary. Arguably the most prominent global economic roadmap is from the IEA, which extensively covers the energy sector.

While the IEA roadmaps are arguably among the most comprehensive, they still are incomplete. Thus, the IEA roadmap excludes a number of relevant sectors from a climate perspective, including parts of the mining sector for example.

For instance, for a global stock index (MSCI World), roughly 30% of the climate-relevant market capitalization is not covered by the IEA roadmaps (e.g. airports, road infrastructure, agriculture) (Financing the Future Consortium, 2014) . This is particularly relevant from an investment perspective, as the limits of economic roadmaps translate into limits for investment roadmaps.

3.3 From economic roadmaps to investment roadmaps

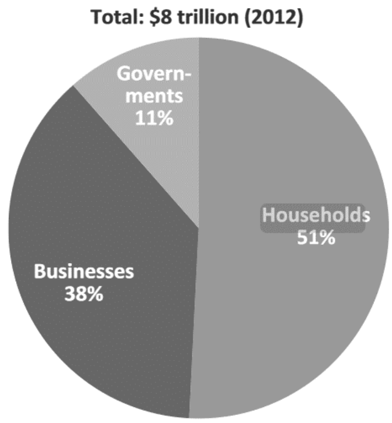
The most prominent organsations currently developing investment roadmaps are the IEA (International Energy Agency, 2014). Indeed, even in an IEA 2°C scenario, the total amount of investment in oil & gas is still higher than in energy efficiency. From a 2° C investment criteria perspective, this suggests that even if some types of oil & gas investment may not *contribute* to 2° C climate goals, these types of investments are not necessarily systematically misaligned with these climate goals. Obviously, this is all the more relevant for mainstream investors and financial institutions seeking to achieve a diversified portfolio.

In 2012, the IEA published the Energy Technology Perspectives (International Energy Agency, 2012), which tried to define the necessary 'additional investment' to achieve 2° C scenarios. They find total investment needs of USD 140 trillion until 2050, USD 36 trillion more than under a 6° C scenario. Crucially, most if not all scenarios still envision some level of investment in high-carbon sectors and technologies. In terms of infrastructure, the energy transition "will require cumulative investment in green infrastructure in the range of USD 36-42 trillion between 2012 and 2030, i.e. approximately USD 2 trillion or 2% of global GDP per year.

Recent investment roadmaps are increasingly informing not only on the levels of investment, but also the expected sources of those investments. Thus, the IEA roadmap breaks down investment by governments, businesses and households for industry, buildings, and transport.

Beyond the issues related to economic roadmaps, most investment roadmaps do not distinguish different types of capital. For instance, translating the energy roadmap for transport into implications for debt financing requires distinguishing development capital in aircraft manufacturing and low-carbon jet fuel, procurement capital for airlines, and investment in airport infrastructures. This distinction is not clear in capital expenditure roadmaps, in particular with regard to R&D financing needs. An additional challenge for capital expenditure roadmaps is the high degree of uncertainty associated with issues such as the changes in capital costs and technology.

Figure 12 Cumulative investment in energy efficiency in the New Policies Scenario by ownership category 2014-2035 (International Energy Agency, 2014)



Notes: Governments include state-owned companies. The investment has been fully attributed to the main investor, although part of the investment might benefit from third-party support, for example, in the case of a government grant for building refurbishment.

The table below highlights the cumulative investment needs by sector and its link to financial actors. The data is sourced from a combination of IEA investment needs estimate from 2014 (International Energy Agency, 2014) and analysis of datasets.

What is critical to highlight in this context is the uncertainty that is associated with these figures and estimates as they are linked to financial actors and underlying actors. This uncertainty is driven by the question as to the investment needs associated with specific technology deployment levels. For example, investment levels have largely stayed flat for solar PV since around 2010 / 2011. Deployment has nearly quadrupled however since then, suggesting a commensurate decline in costs of around 60-80% (2° Investing Initiative (f), 2017). Of course, models can 'forecast' such cost evolutions, but they are inherently uncertain, in particular when the underlying technology is still relatively immature.

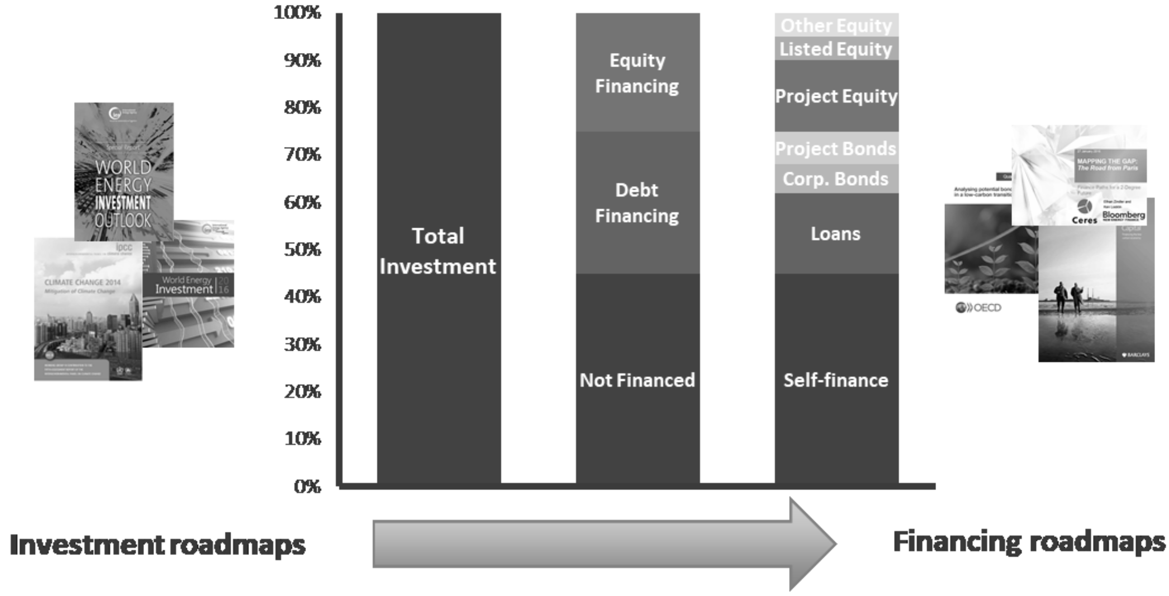
Table 2 Investment needs and links to financial actors by sector (2° Investing Initiative (f), 2017)

INVESTMENT CATEGORY	CUMULATIVE 2DS INVESTMENT ($T, IEA 2014)	OWNERS OF UNDERLYING ASSETS	FINANCIAL ACTORS	MOST IMPORTANT FINANCIAL INSTRUMENTS	EXAMPLE DATABASES
O&G Upstream	$14.1	O&G E&P Companies SPEs (project companies)	Companies (bal sheet), Commercial Banks, Investment Banks, DFIs, Investors	Project finance, Corporate loan (inc. RBL), Corporate Bonds, Listed Equity	Infrastructure Journal (project), Thomson Reuters/ Bloomberg (syndicated debt, bonds)
O&G Transport/ Refining	$4.4	Integrated/refining Companies SPEs (MLPs, Infra Funds)	Companies (bal sheet), Commercial Banks, Investment Banks, DFIs, Investors	Project finance, Corporate Bonds, Listed Equity	
Coal Mining & Transport	$0.7	Mining Companies SPEs (project companies)	Companies (bal sheet), Commercial Banks, Investment Banks, DFIs, Investors	Corporate loan, Corporate Bonds, Listed Equity	
Power Generation	$13.4	Utilities, Equipment Mfgs, SPEs (Yieldcos), Investors, Municipalities, Other (small distributed; households, universities, etc.)	Companies (bal sheet), Commercial Banks, Investment Banks, DFIs, Investors	Project finance, Corporate loan, Project bonds, Leasing, Corporate bonds, Listed Equity	Platts/Globaldata (public deals), BNEF (green only), EnerData
Power T&D	$5.9	Utilities, SPEs (MLPs, Infra Funds)	Companies (bal sheet), Commercial Banks, Investment Banks, DFIs, Investors	Project finance, Project bonds, Corporate bonds, Listed Equity	
Biofuels	$0.9	O&G companies, pure play companies	Companies (bal sheet), Commercial Banks, Investment Banks, DFIs, Investors	Corporate loans, Corporate bonds, Listed Equity	Several public databases
Industry EE	$1.4	Companies	Companies (bal sheet), ESCOs, Gov agencies	Leasing, Corporate bonds, Listed Equity,	Limited data availability except in local/regional markets
Transport EE	$8.1	Households, companies	Retail banks, Auto finance cos, Investment Banks (ABS), Investors	Vehicle Loans, Leasing, ABS	
Buildings EE	$4.0	Households, Companies, REITs, Investors	Retail banks, Commercial banks, Investment banks, ESCOs, Gov agencies	Mortgages, Commercial Mortgages, MBS, CMBS	

3.4 From investment roadmaps to financing roadmaps

Capital expenditure roadmaps, although usually labelled investment roadmaps, provide little guidance for the financing and investment decisions of financial institutions. Turning capital expenditure roadmaps into financing needs roadmaps requires two further steps (see Figure below).

Figure 13 The concept of translating investment roadmaps into financing roadmaps (2° Investing Initiative (f), 2017)

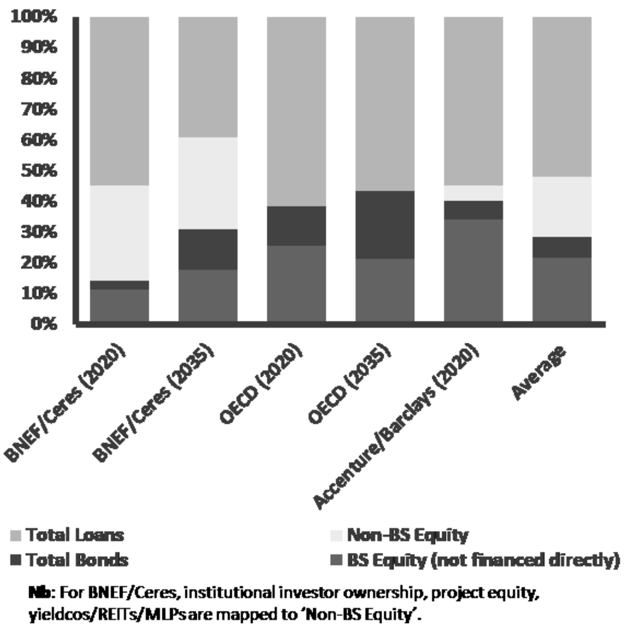


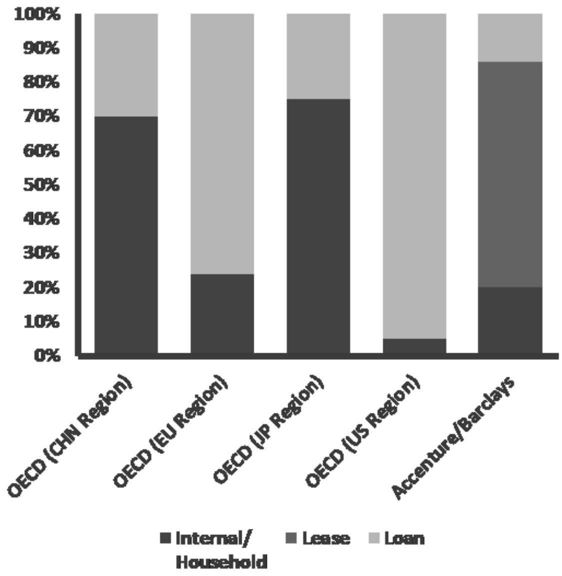
First, capital expenditure volumes need to be broken down by type of capital based on the different stages of technology development. Second, the associated capital needs to be connected to ownership (e.g. companies, households, governments) and financing structure (e.g. equity issuance, loan, retained earnings, etc.), an issue the IEA scenarios have started to address. In the IEA 2014 World Energy Investment Outlook (International Energy Agency, 2014), the IEA, in partnership with the 2° Investing Initiative, for the first time began to explore the financing structure of power companies, oil & gas, and coal companies. The 'sources of financing' analysis broken down by equity issuance, bond issuance, and internal financing for major companies may provide the first step in translating investment roadmaps for the energy sector into financing roadmaps for the finance sector.

Research by Accenture commissioned by Barclays (Accenture / Barclays, 2011) provides the only true role model in this regard. They developed a European scenario for dealing with the financing of a sample of technologies in power production, road transport, and buildings efficiency until 2020. The scenario rests on the analysis and extrapolation of past transactions on these technologies. The authors identified cumulated financing needs of €350 billion in technology development and €1.65 trillion in technology procurement. Equity issuance plays a key role in financing development, while retained earnings, loans, and bonds are the primary sources of financing for procurement. To deliver this future, the finance sector is expected to develop green seed capital, venture capital, and private equity funds to finance innovation, mobilise equity and bonds underwriting businesses to provide expansion and procurement capital and develop the capacity to originate loans for small-scale projects.

The figure below shows the differences in the estimates in terms of financing structures both across roadmaps and across geographies, based on a meta-study by the 2° Investing Initiative. Similar to the investment roadmaps, there is significant uncertainty and differences across the estimates. For example, balance sheet equity (not financed directly, BS equity) in the case of the BNEF / Ceres estimates for 2020 in terms of power financing is around 10%. In the case of the OECD estimate, this number is around 25% and Accenture in turn estimates that figure at around 35%.

Figure 14 Overview of financing breakdown for power (left) and automobile (right) based on a literature review of studies (2° Investing Initiative (f), 2017)





Based on your choice of estimates, the underlying 'benchmark' that can be used to orientate financial markets will differ significantly, not to speak to the underlying uncertainty as to investment levels themselves. Similarly, as shown in the auto sector, internal / Household financing can be anywhere between less than 10% to upwards of 70%.

This suggests that a simple 'translation' as done in this chapter is not the way forward. As will be argued in the next section, climate accounting and a 2°C Portfolio models needs to focus directly on the economic activity and skip the considerations of financing and investment, given its inherent uncertainty. This choice obviously comes at the expense of extracting a notion of ‘financing target’ directly for a financial institution, but has the critical advantage of staying true to the spirit developed earlier in this thesis around economic diversification.

The implication is that portfolio strategies need to orient themselves based on their economic exposure rather necessarily the capital footprint. This economic exposure then, as expressed in their activities and compared to the required economic exposure under a 2°C scenario, creates the basis for developing ‘2°C benchmarks’. The next section will explore how to arrive at this outcome in practice.

Part 2
…And I took the one less travelled by…
The 2°C Portfolio model

4. Climate accounting

4.1 Overview

The discussion in this chapter is based on a previous publication (Thomä, Dupré and Hayne, 2018).

“The first step towards developing an alternative framework for optimal diversification relates to questions of accounting, specifically climate accounting frameworks in financial markets. The origin of these frameworks sits with the development of the first carbon footprinting of listed equity portfolios in 2005 / 2006, pioneered by Henderson Global investors in partnership with Trucost and Pictet AM with Inrate (2° Investing Initiative (a), 2013). Over time, a number of new market entrants (e.g. South Pole Group, Ecofys, MSCI) started developing carbon footprinting frameworks (ibid.).

Climate accounting among institutional investors arguably really started getting traction in 2014 with the Montreal Pledge launched by the UN Principles for Responsible Investment (UN PRI). Since its launch, over 120 investors representing over $10 trillion in assets under management have signed up to the Montreal Pledge, committing themselves to publishing the carbon footprint of their investment portfolios on an annual basis (Novethic, 2015). There are also additional initiatives at the country level, notably Sweden (AP Funds, 2015) and Netherlands (PCAF, 2017).

In addition to private sector initiatives, policymakers have increasingly focused on the question of climate accounting. In 2015, France passed the French Energy Transition Law, which under Art. 173 created a regulatory mandate for French investment managers and asset owners above a certain size to report on their ESG and climate management frameworks, their alignment with national and international climate goals, as well as climate-related financial risk (Schoenmaker and van Tilburg, 2016). Beyond direct legislative interventions, financial supervisors in the Netherlands, United Kingdom, and policymakers in Switzerland and Sweden have initiated supervisory climate analysis and related pilot projects (2° Investing Initiative (a), 2016). At the international level, the Financial Stability Board initiated a Task Force on Climate-Related Financial Disclosures set to define a climate reporting framework (Financial Stability Board, 2017). This has been coupled with research initiatives at universities around framing stress-tests and developing policy initiatives (Campiglio et al., 2017).

Despite this growing body of practitioners driven literature on climate accounting (Kepler-Cheuvreux, 2015), there is very limited academic literature on the underlying accounting frameworks, options, challenges, and shortcomings that govern these applications. Moreover, the literature that does exist tends to focus on data shortcomings (Hoepner, 2016) and questions of impact (Doda et al., 2015). This chapter seeks to identify some of the key accounting principles currently used in the context of climate accounting in financial markets and discuss their relative merits and applications. Crucially, the chapter emphasises the underlying accounting principles deployed as they relate to climate accounting frameworks, specifically accounting rules related to the unit of accounting, normalisation rules, allocation and consolidation rules, and accounting boundaries.

The discussion of the application of the related accounting rules and frameworks will focus on what is described in the academic and practitioners literature as ‘climate friendliness’, ‘climate performance’, or ‘climate alignment’ accounting (2° Investing Initiative, UNEP-Fi, WRI, 2015), that is to say the discussion will not extend to questions of climate risk accounting. While climate risk measurement has its own set of challenges (Andersson, Bolton and Samama, 2016), the underlying accounting frameworks deployed in climate risk assessments tend to be consistent with the accounting rules applied more generally in financial risk assessment (Battiston et al., 2017). The paper will also not discuss the question of corporate reporting and data availability related to financial instruments, except as it relates to questions of accounting boundaries.

The chapter is thus specifically designed to focus on accounting challenges as they relate to climate assessments of financial portfolios. Crucially, most of the reporting guidance focuses on questions of choices of datasets and perhaps to questions of units of accounting and data estimation techniques, as opposed to underlying accounting techniques. It is this gap that this article seeks to fill. Indeed, as this article will demonstrate, despite the fact that most of the attention in sustainability accounting relates to the availability and quality of underlying sustainability data, the accounting of this data can be an equally significant challenge.

4.2 The basis of the analysis

The analysis of accounting principles relies on a combination of empirical as well as theoretical sources. In providing an analysis of climate accounting principles, this article builds on a range of sources highlighted below.

One of the core sources involves a literature review of market studies related to climate accounting services provided by data providers and consultants, two of which the lead author was involved in writing (2° Investing Initiative (a), 2013) (2° Investing Initiative, UNEP-Fi, WRI, 2015). These market studies provide a holistic overview of climate accounting principles as applied by investors since all investors engaged in climate accounting rely in one form or another on the services from data providers and consultants covered in these market studies. As a result, an analysis of these services provides a relatively comprehensive overview of the state of accounting and data principles applied by investors. Given evolutions in markets, where necessary the article complements the market review with additional information as to more recent developments, where appropriate.

In addition to analysing the 'supply' of climate accounting, the article also builds on the engagement done by the authors with institutional investors. As part of this research, the author interviewed over 100 institutional investors as to their climate accounting approaches and conducted direct portfolio analysis with over 250 institutional investors as part of an EU-funded research project on 2°C scenario analysis. For data confidentiality reasons, not all investors chose to disclose their participation in the scenario analysis pilot and/or the interviews. The interviews were not conducted as part of a specific research project and thus did not involve a specific questionnaire. As a result, the results of the analysis do not include quantitative findings from these interviews as to specific accounting preferences or choices. Indeed, the technical analysis of accounting choices is not influenced by popularity, but technical applicability. As a result, the integration of the learnings from these interviews involves where relevant a discussion of approaches (anonymised where required) with regard to accounting principles, as well as caveats or challenges identified in these interviews. This material ensures a comprehensive coverage of approaches as they relate to accounting principles and can identify challenges not necessarily arrived at through a theoretical review of accounting principles. At the same time, as highlighted above, these interviews do not satisfy standards of rigour to inform any conclusions independently or derive quantitative findings.

The third source involves the technical application using sample climate and financial data for the purpose of illustration and 'testing' of approaches, in order to either illustrate the implications of using different accounting rules and/or the feasibility of one or the other approach. The data here relies on Bloomberg financial data and carbon footprint data, sourced from annual reports, as well as third party data sources where relevant.

The point of departure for the choice of accounting principles reviewed in this article is governed by the key principles found in traditional accounting frameworks (GAAP, IFRS) and broadened to reflect the key accounting debates as they relate to climate impact issues, notably allocating responsibilities (Thomä (b) et al., 2015) and the impact boundaries. At the same time, questions like the temporal and operational boundaries can be found in traditional accounting frameworks.

4.3 Key accounting principles

As outlined above, the key areas of analysis in terms of accounting principles apply to the unit of accounting, the normalisation principles applied in order to arrive at performance benchmarks, the allocation and consolidation rules, and accounting boundaries. Each of these will be discussed in turn.

4.3.1 Unit of accounting

The unit of accounting is arguably the most basic element when it comes to accounting principles, and indeed the one that has received the most attention in the academic and practitioners literature. The accounting units operate in three distinct categories (2° Investing Initiative, UNEP-Fi, WRI, 2015): carbon metrics, green / brown metrics, and climate scores. Each of these will be illustrated using the automobile manufacturer BMW as an illustrative example of their application.

Carbon footprinting is the most commonly used metric for climate friendliness and an integral part of the Montreal Carbon Pledge (Novethic, 2015). For 15 years, companies have used the GHG Protocol standard to calculate their GHG emissions (Pattberg, 2017). Over 5,000 companies in 2014 used the GHG Protocol approach to report to CDP (formerly Carbon Disclosure Project), with most reporting GHG emissions information (2° Investing Initiative, UNEP-Fi, WRI, 2015). Given the growth of such data over time, a large number of organisations use it to estimate and compare the carbon footprint for companies and their value chains and for portfolios of companies.

The key question for financial institutions is the carbon footprint of the portfolio or the financed emissions. The 2° Investing Initiative reviewed the state of the art of such financed emissions methods in 2013, and the number of data providers has continued to grow since then, with a particular focus on listed equity (due to both the size of typical equity portfolios and data availability for listed companies) (2° Investing Initiative (a), 2013). One key question for GHG emissions accounting relates to data quality (Hoepner, 2016) and the inability to capture low-carbon alternatives, which do not emit GHG.

Green/brown metrics are "sector-specific indicators distinguishing between climate solutions and climate problems. This category includes two main types of metrics: 1) ratios of exposure to different technologies or business lines and 2) sector-specific energy or emissions intensity/efficiency metrics." (2° Investing Initiative, UNEP-Fi, WRI, 2015)

Finally, climate scores are qualitative indicators that combine quantitative and qualitative assessments to develop a scoring system. Table 1 summarises the different units.

Table 3 An overview of different climate units of accounting (2° Investing Initiative, UNEP-Fi, WRI, 2015)

	DESCRIPTION & EXAMPLES	APPLICATION	PROS	CONS
CARBON FOOTPRINT	Cross-sector portfolio-level assessment of the exposure of a portfolio to greenhouse gas emissions of its investees.	• Connecting the dots between portfolios and climate change • Project finance screens • Real estate energy efficiency measures • Engagement on short-term corporate emissions reduction • Portfolio construction for listed equities ideally together with green / brown exposure metrics • Public communication & reporting	• Broad information on climate intensity of sectors • Prominence among corporates and experience • Standardization of corporate reporting across sectors enables portfolio reporting	• High uncertainty associated with data at financial asset level • Incomplete coverage • Lack of accounting standard • Data volatility associated with external factors when normalizing
GREEN / BROWN METRICS	Sector-specific indicators distinguishing between activities and technologies that are climate solutions and climate problems.	• Negative / positive screening for project finance • Negative screening and 'green' targets for corporate bonds (ex. Green bonds) • Portfolio construction for listed equities together with carbon metrics • Engagement on investment in different technologies	• Quantitative indicator with high data transparency • Relevant indicator for corporate management	• Only applicable for a number of key sectors • Challenge of distinguishing relative climate friendliness within categories (e.g. gas vs. coal) • Currently no format to aggregate data across sectors
CLIMATE (ESG) SCORES	Climate-related indicators / scores are qualitative indicators based on quantitative and qualitative climate indicators, including carbon and green / brown exposure metrics.	• Engagement with companies on corporate strategies • Engagement on climate issues together with non-climate issues	• Summary indicators capturing a range of different factors • Established frameworks	• Black box • Risk of greenwashing • Not directly linked to a specific strategy

The indicators will briefly be elaborated on a stylized example for all the three indicators using BMW as the case study (BMW Group, 2016).

The most common indicator is GHG emissions. BMW's GHG emissions reporting is among the most detailed in the world, breaking down Scope 1 (related to direct GHG emissions), Scope 2 (related to indirect GHG emissions associated with electricity and heat consumption) and Scope 3 (related to other indirect GHG emissions).

The challenge is that all these values are reported at the group level and not connected to actual economic activities by BMW. Thus, the user of this information does not know how much GHG emissions are associated with any individual car sold, nor how each unit of GHG is broken down by business segment. BMW is the rare example where Scope 3 gets reported, which in the case of BMW make up around 95% of their GHG emissions (Figure 18). Currently, over half of GHG emissions data at company level for portfolios is estimated, even when considering just Scope 1 and Scope 2 and the number gets even higher for Scope 3 (Hoepner, 2016).

When shifting to green / brown shares, the problems are different, but the challenges remain similar. Aggregated 'green' shares for example as intermediated by data providers like FTSE Russell cannot discriminate between hybrid and electric vehicles, products with relatively significant different profiles.

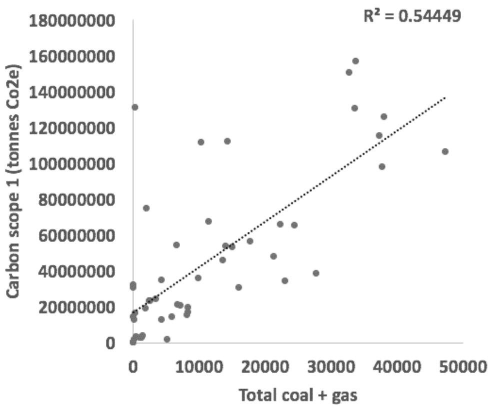
Finally, there is qualitative reporting, which for all its upside in seeking to provide a 'holistic' picture, relies on qualitative assessments and weightings of different factors. Thus a grading of BMW's climate strategy independent of its operations may yield different results by different ESG data providers.

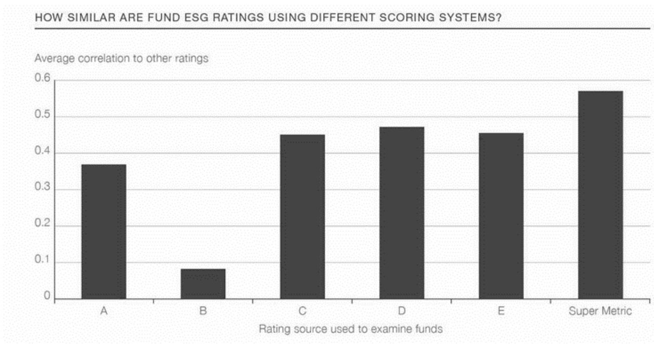
The relative merits of different accounting units are a function of the use case and the underlying data quality that informs each of these indicators, which is outside the scope of this article. However, it is relevant to highlight that the choice of indicators may not be correlated. Research by Schroeders shows a low correlation between different ESG scores (Howard, 2017). Other research suggests that the overlap in ratings ranges between 19% to 60% (Chatterjee, 2012). They conclude that "low convergent validity between SRI raters is not only driven by different theorisations, but also by low commensurability among most pairs of raters."

Similarly, indicators may not correlate well across types of indicators. As a simple analysis demonstrating this point, the author mapped the correlation between the absolute Scope 1 GHG emissions, as measured by Trucost, for a sample of 50 electric utilities and their absolute installed capacity for coal power and gas power of the associated electric utilities (see Figure below).

While correlated, as would be expected, there are a number of utilities with significant outliers, related both to the underlying uncertainty of the data (notably related to estimations of production associated with installed capacity), but also the fact that indicators like installed capacity do not capture the complete business of a utility.

Figure 15 (**a**) The correlation between Carbon Scope 1 emissions and installed coal and gas power capacity for a sample of 50 electric utilities, based on Trucost GHG emissions data and GlobalData electric power data; (**b**) The correlation between ESG Fund ratings using different scoring systems (Thomä, Dupré and Hayne, 2018)





(b)

(a)

4.3.2 Boundary principles

A key challenge for corporate and financial accounting, as well as for the issue under discussion here, is the question of the accounting boundary. When it comes to the unit of accounting, it is not just a question of defining the unit, but also the boundary with which to determine the unit. A range of boundaries may be relevant, notably temporal boundaries (i.e. which time horizon is covered by the accounts), ownership boundaries (i.e. what is the scope of corporate structures covered by the accounts), and business activity boundaries (i.e. what is the scope of business activities covered by the accounts).

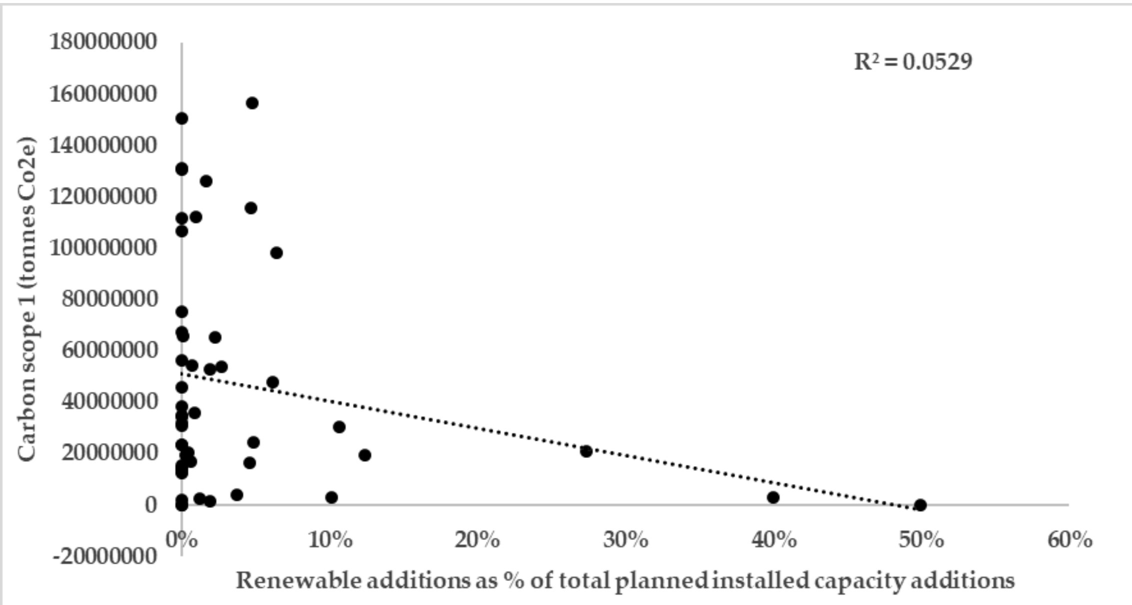
There are of course other boundary issues that may arise, but it is these three that are considered the most salient for the question of climate accounting principles. While each of these may warrant their own deep-dive articles, this article will seek to constrain itself by simply mapping the key questions and issues associated with the accounting boundary principles. Each of the three boundary issues flagged above will be discussed in turn.

One key boundary question related to climate accounting is whether backward or forward-looking indicators are considered. The three options in this regard are 'point-in-time' indicators, usually covering the last year, 'historical cumulative' indicators, based on cumulative actions or historical trends, and 'forward-looking' indicators based on some level of forward-looking analysis.

All financed emissions frameworks rely on point-in-time indicators (Kepler-Cheuvreux, 2015). At the same time, there are some attempts to start considering trends (Carbone4, 2016), as well as consider historical cumulative GHG emissions (Heede, 2013). The historical approach has been deployed in the context of allocating legal responsibility to major GHG emitters, as done recently in the case of a Peruvian farmer against RWE (decision pending) (Minter-Ellison, 2017).

One critical aspect in this respect is that the temporal boundary is critical in terms of driving results and may lead to non-correlated results. For example, point-in-time indicators of the share of high-carbon power production for electric utilities (expressed in Scope 1 CO_{2e}) show almost no correlation – positive or negative – with planned renewable power capacity additions (Figure below). In other words, electric utilities that are more high-carbon currently do not necessarily invest more or less in low-carbon alternatives in the future. This lack of correlation, suggests that temporal boundary choices are critical for determining the climate unit of accounting and may lead to inconsistent results.

Figure 16 The correlation between Scope 1 GHG emissions of a sample of 50 global listed electric power utilities and the share of renewable power in planned capacity additions, based on Trucost Scope 1 data and GlobalData power investment data (Thomä, Dupré and Hayne, 2018)



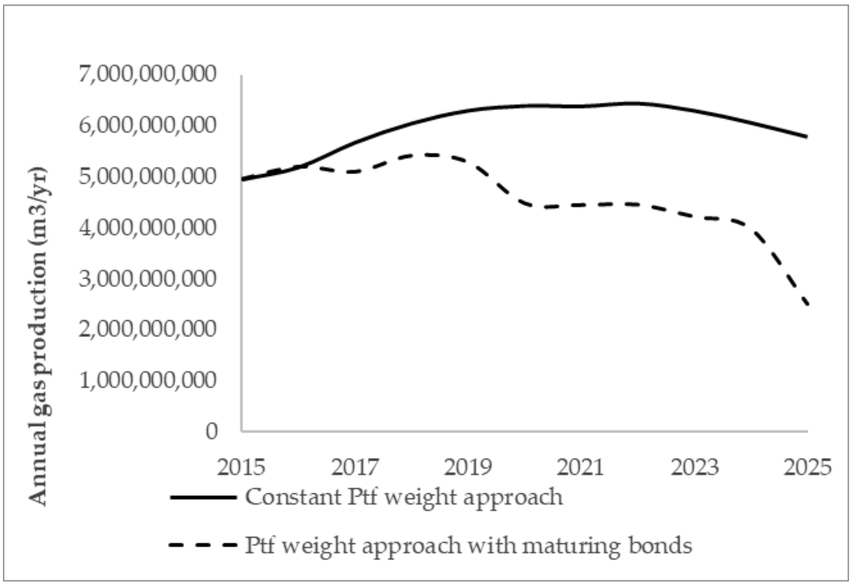
Another key boundary issue relates to ownership boundaries. For corporate accounting, this is a critical element, as it relates to questions of how to account subsidiaries in annual accounts and partially owned assets. There is a rich literature as to the rules and principles for accounting these types of assets. Notable approaches in this regard relate to the 'equity share' accounting, which allocates economic or financial activity based on the equity stake in the underlying asset or subsidiary. Another approach is the management control approach, where 100% of the activity gets allocated to the entity that has management control of the asset or subsidiary. Thus, if the entity owns 51% of a power plant, it would get allocated 100% of the installed capacity and associated production.

The choice of these or other approaches may be specific to the accounting objective, and indeed will not necessarily be consistently applied in one annual report of a company. While critical from a climate accounting perspective, the issues here are the same as one would see in traditional corporate accounting and thus not necessarily of significant additional interest for the purpose of this chapter. Suffice it to say that ownership boundaries are critical at the entity level in order to correctly and comprehensively capture a company's activity. At the same time, it is an issue that is of primary concern at the entity and not portfolio level, insofar as the portfolio will import the accounting choices made at the entity level.

At the portfolio level, the ownership boundary that is of particular interest from the perspective of climate accounting is the question of the maturity of credit instruments. The issue here can be summarised as follows: When a company projects future activities or revenues, it does this based on the current fixed asset base and commitments as to the evolution of that asset base based on investments and mergers and acquisitions. In the case of a credit portfolio with maturities, this future commitment does not exist by default, since the instruments mature and it is not given that the instruments will be refinanced (even if likely), nor that the portfolio manager will reinvest in the same company or instrument. By extension, the accounting assumptions taken around maturing instruments influence 5 or 10-year forward-looking analysis of the portfolio.

The figure below demonstrates the impact of this choice. Here, the annual gas production of a corporate bonds portfolio allocated based on the portfolio weight approach, is shown over a 10-year time horizon. The line shows the trajectory assuming no maturity of bond instruments, whereas the dotted line represents the annual gas production assuming the maturity of bond instruments. In the second case, the gas production in the portfolio is reduced by 50% over a ten-year time horizon by the sheer merit of maturing instruments.

Figure 17 The annual gas production of a corporate bonds portfolio, allocated based on the portfolio weight approach, accounting for maturing corporate bonds and keeping corporate bonds constant, based on portfolio data and GlobalData forward-looking gas production estimates (Thomä, Dupré and Hayne, 2018)



The choice for one or the other cannot be described in absolute terms but is rather a function of underlying strategies. Investors that assume a refinancing approach may be more inclined to assume no maturity, whereas investors that specifically target no refinancing may be inclined to go for the dotted line. Allianz for example as part of its coal divestment strategy has not committed to selling bonds in their portfolio, but rather excluding coal from future investments, based on the categories they have defined (Allianz, 2017). In their case, the dotted line, at least when considering coal production, may be more appropriate. Given the general view of refinancing, however, the straight line may be a more appropriate general application.

The final key boundary issue of interest here is the boundary of a business activity. From a climate perspective, there is a key hierarchy of business activities that have a more or less significant impact on climate change. These can be mapped differently to the business segments of a company and its associated financial instruments. Around 20% of a typical financial portfolio account for around 80% of the GHG emissions of associated companies (Exane PNP Paribas, 2015).

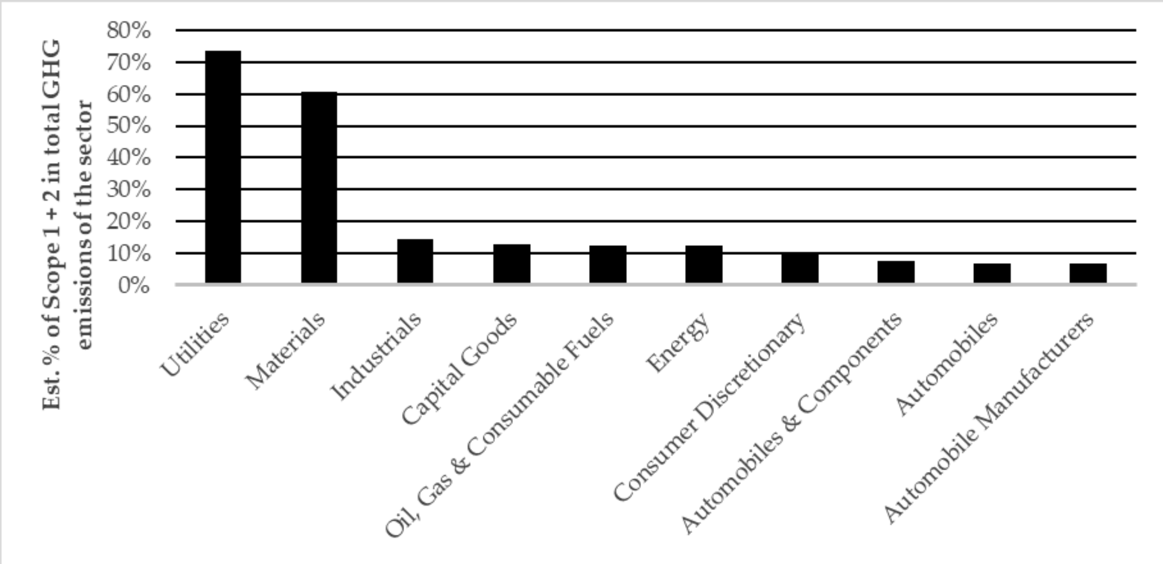
By extension, climate accounting for financial portfolios may limit itself to only specific business segments of investee companies and specific parts of the portfolio. For example, the

2°C scenario analysis of TPT Retirement Scheme (TPT Retirement Scheme, 2017) and AXA (AXA Group (a), 2017) only considers around 15% of the portfolio. Similarly, the analysis of Trucost for ERAFP (ERAFP, 2016) on the power sector only looks at the power generation activities of utilities and does not look at their other business segments (e.g. distribution, mining). The boundary issue on climate is thus not just one of the scope of corporate ownership, but also activity.

Part of the boundary issue is a function of the units of accounting. If the unit of accounting is power capacity, for example, other activities are obviously not considered. The question here then becomes the scope. For example, is the power capacity owned by Apple, which represents a rounding error in the overall revenues of the company, considered together with those of electric utilities or not. These types of choices are less accounting choices than data choices.

For GHG emissions, however, the boundary issue becomes quite significant. Current carbon footprinting frameworks rely almost exclusively on Scope 1 and Scope 2 GHG emissions (Kepler-Cheuvreux, 2015) In some cases, supply-chain emissions are estimated, as is the case for Trucost (ibid.). Thus, while they seek to cover the complete universe of business activities of a company, they do not cover the complete universe of climate impacts of the products and services associated with these business activities. Crucially missing from these business activities are the GHG emissions from the use case of the product. This implies that for 8 of 10 sectors, less than 20% of the climate impact is covered in the analysis (see Fig. below). While there is some inherent uncertainty in the data estimates, even a somewhat more benign estimation still would suggest that the analysis does not cover the majority of GHG emissions.

Figure 18 The share of Scope 1 and Scope 2 in total GHG emissions of the sector, based on Beyond Financials data (Thomä, Dupré and Hayne, 2018)



4.3.3 Allocation principles

Once the unit of accounting is defined, the next key accounting challenge is how to allocate the economic activity of a company to financial instruments. Indeed, this accounting principle is arguably the most complex, since it has no real role model in traditional accounting frameworks. Traditional corporate finance research looks at ways to minimise the impact of financial institutions' strategies on share prices. Indeed, organisations like State Street have dedicated departments to help financial institutions transition their portfolios without impacting share prices (State Street, 2017). Classical corporate finance literature in the spirit of Modigliani-Miller seek to demonstrate the fungibility of different asset classes in influencing corporate finance conditions (Modigliani and Miller, 1958). From the perspective of climate, the interest tends to be in actual seeking to impact investment in the real economy, in favour of investments consistent with the transition to a low-carbon economy and global climate objectives.

In this context, allocating responsibility or accountability of economic activity to financial instruments cannot rely on a rich body of literature for guidance, in particular when it comes to allocating economic activity to different asset classes without double counting (i.e. allocating the same unit of economic activity to two different financial instruments).

In response to this challenge, the thesis defines two types of allocation principles, namely the 'portfolio-weight' approach and the 'balance sheet' approach.

The equation reflecting these two approaches can be summarised as

Equation 1 $$u_f = \sum_i^n u_i \times \frac{p_i}{a}$$

where u_f is the climate unit allocated to the portfolio, u_i the absolute climate unit of company i, p_i the value of the financial instrument of company i in the financial portfolio, and a the allocation factor. The key question here then is the definition of a.

The balance sheet approach, arguably the more common between the portfolio weight and the balance sheet approach, involves allocating economic activity to the balance sheet based on the definition of a fixed allocation key. Within this approach, different applications are explored.

The first option for a is allocating all economic activity to the equity instruments of a company, in the logic of allocating 'ownership' of economic activity to only those instruments that directly account for ownership. This approach is currently being applied by the Swedish pension funds (AP Funds, 2015). While internally consistent and an attractive solution for those financial institutions exclusively invested in or concerned with accounting equity instruments, it gives rise to the double counting issue that if all economic activity is allocated to equity and then allocated again – in some to be determined formula – to credit instruments, it gets counted twice. Crucially, the equity principle cannot by design be applied to other financial instruments.

The upside of this approach, however, is that because equity ownership can be expressed in percent of the total, the allocation rule is not biased by fluctuations in market prices (e.g. share prices). Moreover, there exists some logical consistency in allocating all economic activity to its owners. Indeed, this approach is the only area where an extension of traditional corporate consolidation rules can be extended to financial instruments, in the spirit of the way companies prepare their corporate accounts when considering their subsidiaries.

Of course, allocation rules can also be defined based on either line items in a balance sheet, notably enterprise value, an approach chosen by Mirova for the climate accounting of their portfolios (Mirova, 2017). The upside here is that this approach avoids double counting and allows for applicability across different asset classes. The downside is that the approach is highly sensitive to market prices. In other words, intensities will fluctuate as enterprise value fluctuates. While not of primary concern here, there can also be challenges for non-listed companies in deriving their enterprise value. Finally, the approach creates an arbitrary equivalence between different asset classes, which may not be intuitive and correct, since they serve fundamentally different functions in many cases, especially when it comes to climate change (Grüning et al., 2017).

The alternative accounting principle is allocating economic activity based on the portfolio weight of the company in the portfolio. In this case, a represents the size of the portfolio itself. It is the approach chosen in the ESG ratings of both MSCI (MSCI, 2018) and Morningstar / Sustainalytics (Morningstar, 2017), as well as the climate ratings of ISS-Ethix / CDP (CDP, 2017). This approach is commonly used to weight normalised or scored indicators rather than allocating absolute climate units, as it represents the relative weight of different scores or intensities in the portfolio.

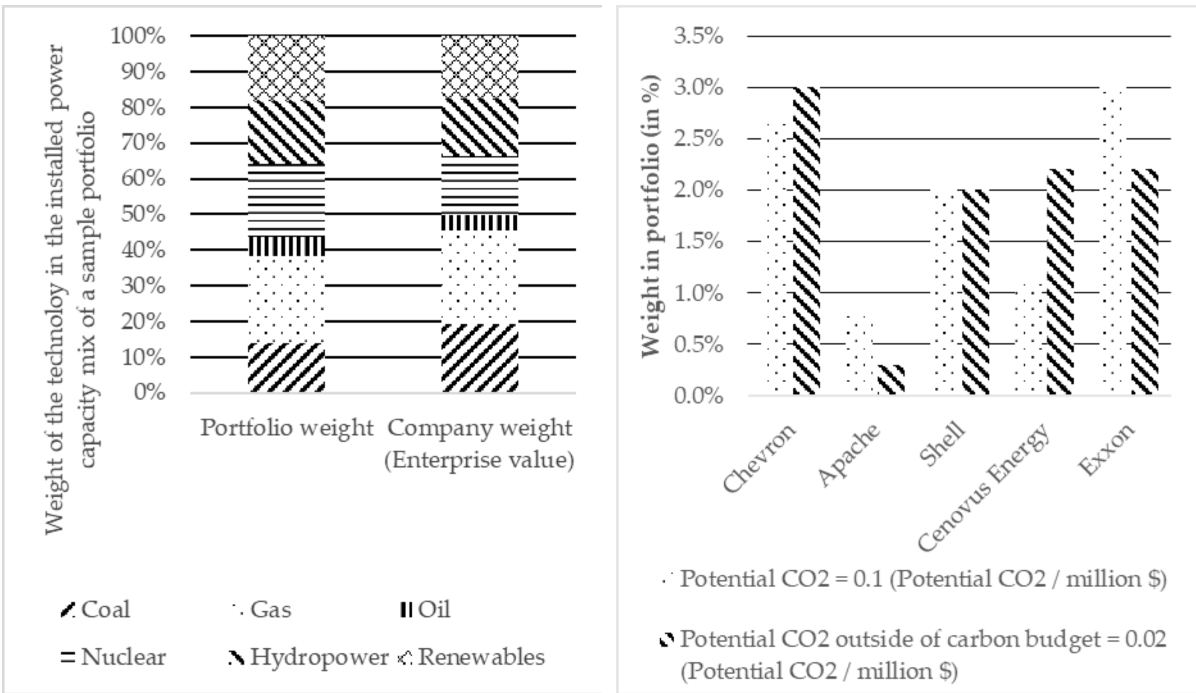
While the balance sheet approach described above can be said to be more intuitive for equity portfolios, the portfolio weight approach is more intuitive for credit portfolios, since it can be said to represent the capital allocation decision of the portfolio manager behind the portfolio, given the discoverability of book value for credit instruments. In other words, the portfolio value of a credit instrument, as measured in book value, can be said to represent the money allocation of the portfolio manager, whereas the same is not necessarily the case for equity portfolios, given the potential fluctuation of the book and equity value of a company. An investor, who invested in Tesla in 2013 and still holds the stock will have a different portfolio value in their portfolio today than four years ago.

Another factor that speaks to the portfolio weight approach is the more intuitive link to financial risk. While out of scope, accounting based on portfolio weight allows for a representation of the size of the exposure of the portfolio to the company.

The figure below shows the implication of choosing different allocation rules for a sample corporate bonds portfolio. The actual portfolio composition relies on a corporate bonds portfolio provided by a European insurance company slightly adjusted for the purpose of this study for confidentiality purposes. The portfolio represents a composition of instruments from 2016 invested in developed markets. The results are illustrative, and thus the exact composition of the portfolio is not of primary concern here, it is rather to demonstrate that the results will differ based on using different approaches. While in aggregate the results do not fluctuate wildly, the different measured technology weights are arguably significant. Thus, the weight of coal power capacity in the portfolio weight approach is 13.8%, versus 19.4% in the company weight approach using enterprise value.

As highlighted above, another conclusion of the analysis is that portfolio weight is more intuitive for financial risk assessments and considerations, given the relevance of the portfolio weight for exposure. On the flipside, the share of a portfolio in a company's outstanding debt is secondary to risk considerations. The figure below demonstates the potential disconnect. It shows the weight of five different oil & gas companies in a portfolio, where the residual portfolio weight has a carbon intensity of zero, that is consistent with a potential future CO_2 intensity of 0.1 (Potential CO_2 emissions / million \$ invested) or consistent with a potential CO_2 intensity outside of the carbon budget of 0.02 (Potential CO_2 emissions / million \$ invested) (Carbon Tracker Initiative, 2017).

Figure 19(**a**) The power mix of a sample corporate bonds portfolios based on two different allocation rules, based on Bloomberg and GlobalData; (**b**) The differences in portfolio weight associated with a consistent carbon footprint of the portfolio for five different oil & gas companies, based on Carbon Tracker Initiative (2017) and Bloomberg data (Thomä, Dupré and Hayne, 2018)



(a) (b)

The results show that identical emissions, allocated based on a balance sheet approach (in this case allocated based on market capitalisation of the company) is linked with significantly different portfolio exposure to underlying carbon-intensive companies. Given that the analysis assumes the rest of the portfolio contains no carbon whatsoever, the results show that identical footprints can lead to differences in the percent of the portfolio exposed to climate-related transition risk of less than 0.5% to up to 3%.

4.3.4 Normalization principles

Normalization is a critical part of climate accounting in financial markets as it is required to derive performance benchmarks related to climate. The absolute carbon emissions of a company for example or absolute installed coal power capacity may not be meaningful without understanding the size of the company itself. A large electric utility would be expected to have more installed coal power capacity than a smaller utility, et ceteris paribus, and of course more coal power capacity than a non-utility. Some climate strategies related to climate accounting do not require normalisation, e.g. an investor that does not want to invest in companies that own any coal-fired power plants does not need to know any more information other than whether the company owns coal-fired power.

Mergers and acquisitions, as well as changes to business segments, also make it difficult to work with absolute GHG emissions data for example, since this number may increase or decrease as a function of changes in the company's size and not related to actual business changes. The cement company HeidelbergCement, an example explored further below, demonstrates this.

However, the majority of investor strategies will demand some contextualization. For example, if an electric utility, hypothetically, owns 1 GW of coal-fired power and 20 GW of renewable power, this context would be relevant, even if in absolute terms 1 GW is a significant amount of coal power. Thus, investors that have chosen to divest from coal (e.g. AXA, Allianz) have in almost all cases defined thresholds in terms of the share of coal in a company's business activities (42-43).

The equation underlying this accounting principle is

Equation 2 $$cl_i = \frac{u_i}{n_i} \times c$$

Where cl_i is the normalized climate intensity of company i, u_i is the original climate unit of company i, n_i is the normalization factor for the company I, and c is a constant that may be applied to express the outcome in a desired unit (e.g. 1 million $, a ton of cement). The same equation can be expressed at portfolio level albeit slightly adjusted

Equation 3 $$cl_f = \frac{\sum_i^n u_i \times \frac{p_i}{a}}{\sum_i^n n_i} \times c$$

Where cl_f is the normalized climate intensity of the portfolio.

In terms of normalisation, there are two types of accounting approaches that can be applied. Climate data can either be normalised by economic activity, expressed in economic units (e.g. capacity, production), or company size, expressed in monetary units. The approach of normalising by economic units implies that the nominator, which represents the identified climate unit (e.g. installed renewable power capacity in MW, GHG emissions) is normalized either by a unit of output or production capacity. In the case where the unit in the nominator and denominator is identical, the related indicator can then be expressed in percent, or otherwise as a specific unit.

For GHG emissions, by design, these can only be expressed to signify the percent of types of GHG emissions (e.g. Scope 1, Scope 2, Scope 3) in total emissions. The choice to normalise by economic activity is applied in the climate accounting and reporting frameworks developed by Trucost for ERAFP (ERAFP, 2016), and the approach taken by the Swiss government in the context of the 2°C scenario analysis pilot launched in 2017 (2° Investing Initiative (b), 2017).[24]

The key challenge in terms of normalising by economic activity is that this only allows for business-segment specific analysis and thus by extension does not lend itself to cross-business segment and portfolio-level aggregation. It is not possible to aggregate indicators with different denominators (e.g. GHG emissions / MW and GHG emissions/ton of cement) without developing a conversion factor, which likely, in turn, requires some variant of scoring (see previous sections) in order to count as a unit of accounting. By extension, normalising by economic activity can be an effective approach at stock-picking and portfolio analysis, but not in the context of seeking to report aggregated indicators (Thomä (b) et al., 2015).

An alternative to normalising by economic activity is to normalise by company size, expressed in monetary units. Normalizing by company size can also be interpreted to normalise by financial activity if elements like market capitalisation or a company's balance sheet are set to

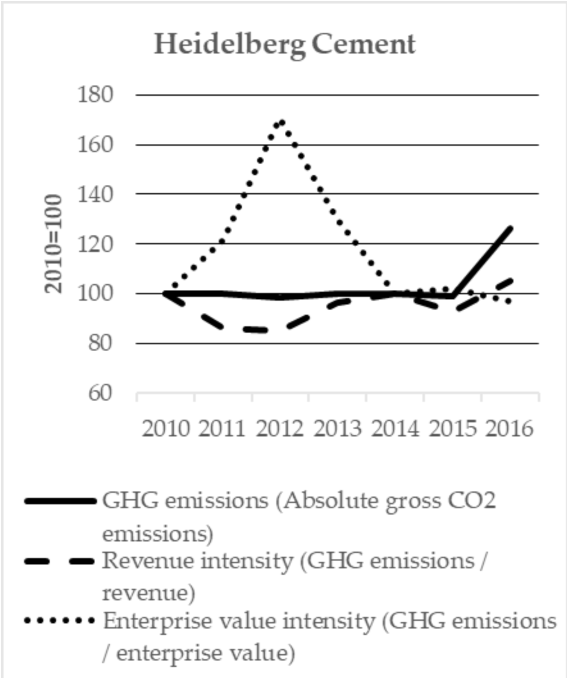
[24] Disclaimer: The author was involved in leading this pilot.

reflect future financial returns. all financed emissions methodologies currently used by financial institutions in the market use this normalization approach. It solves the question of aggregation by providing a denominator that exists for and can be consistently applied by all companies. The most prominent types of indicators in this regard are revenues, market capitalization, or enterprise value (Kepler-Cheuvreux, 2015).

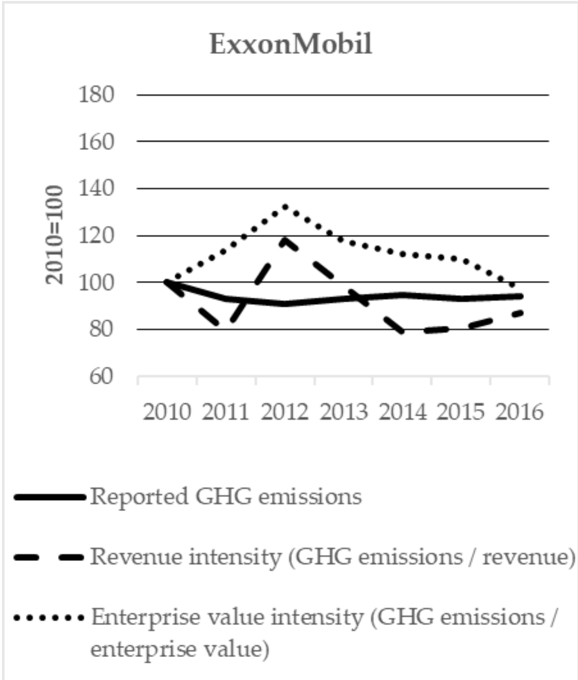
The use of the enterprise value for an allocation key here is different from the use of enterprise value for normalization purposes described above. This is because in the one case the enterprise value is used to normalize the climate unit in order to derive an intensity for a company (or portfolio). In another case an absolute volume of GHG emissions, for example, is allocated to individual financial instruments based on the weight of the financial instrument (in monetary terms) in total enterprise value.

Given that this indicator, however, has to rely on monetary units, it can create biases in the results. The following example for an oil & gas company (ExxonMobil) and a cement company (HeidelbergCement) illustrate this point. The figure below shows the absolute GHG emissions (Scope 1 and Scope 2) for each company and the normalised GHG emissions for the period 2010 to 2016. The results demonstrate the significant volatility embedded in the denominator when normalising by revenue or enterprise value. While not consistent across both companies, normalised results fluctuate wildly even if absolute GHG emissions do not move materially.

Figure 20 (**a**) The absolute gross Scope 1 and Scope 2 GHG emissions of HeidelbergCement and the intensity normalised by revenues and enterprise value respectively; (**b**) The absolute gross Scope 1 and Scope 2 GHG emissions of HeidelbergCement and the intensity normalised by revenues and enterprise value respectively. (Thomä, Dupré and Hayne, 2018)



(a)



(b)

The relative stability in absolute GHG emissions suggest the relatively stable scope of company economic activity, but changes in prices (revenues) and/or the balance sheet (enterprise value) lead to these fluctuations. Interestingly, in the case of ExxonMobil, as ExxonMobil expands its balance sheet through increased debt issuance, and by extension increases its enterprise value as its stock price does not adjust, the normalised GHG emissions intensity goes down. While not in the scope of this chapter, this suggests that this type of normalisation may be inversely correlated with risk trends as a more leverage company will lower its GHG emissions but potentially increase its credit risk. To highlight the challenge with revenues using an example for a different sector, Ferrari might sell one car for two or three cars sold by BMW, even while the revenues or sales might be identical. The climate impact of each, however, is obviously different.

While in both cases normalisation by revenue is associated with lower volatility, volatility is still significant around +/- 20%. For enterprise value, this number jumps above 60% in the case of HeidelbergCement. Crucially, exogenous indicators drive this volatility, rather than the actual ‘climate performance’ or impact of the company. Thus, while this accounting approach allows for aggregation, it can create significant biases in the interpretation of climate accounting at individual security level and by extension may not be applicable for the implementation of passive or active investing strategies, as well as company engagement.

4.4 Discussion of results

The previous section highlighted the range of accounting choices made in the context of climate accounting for financial portfolios. The range of choices and evidence of their application demonstrate that the market currently is far from defining a standard. To use one example, the pilot project by the Swiss government on 2°C scenario analysis actually used two different allocation rules for credit and equity portfolios and a normalization factor based on economic activity (2° Investing Initiative (b), 2017), with all three accounting choices inconsistent with the approach used by Mirova for example (Mirova, 2017). That is not to say that the choice of one or the other is more appropriate, rather than these accounting choices are made in a vacuum, lacking a discourse and academic grounding in an accounting framework fit for purpose for the issue of climate change.

While these different pilots involve different accounting choices, many of the accounting questions can be answered by resorting to financial accounting approaches, for example when it comes to questions of boundaries of reporting and data consolidation rules. At the same time, some accounting issues require new approaches.

A review of key accounting principles suggests that there is in many cases not generally one principle that rules them all, but the most appropriate accounting principle depends on the use case. Crucially, the choice of that principle will have significant impacts on the final results. Each accounting issue defined here by itself drives material differences in the results identified, with in some cases no correlation between the two different indicators/rules and perhaps even negative correlations. The model development thus by design needs to be sufficiently flexible to allow for the different accounting approaches developed in this chapter.

5. Current climate data frameworks

5.1 Overview

The question of unit of accounting was addressed in the previous chapter. Of interest here is the question of data sources and data mobilized for the model.

Before jumping into each of the data categories, it is perhaps worthwhile to briefly review sources of climate-related data that can inform these metrics. The following discussion is based on a previous publication of the author, co-authored with Christopher Weber (2° Investing Initiative (c), 2017)

"The word "data" describes three sets of information: primary data, secondary data, and performance data. Each type of data has financial components and nonfinancial components and is collected by three different sources: by companies as the owners of physical assets, by public sector agencies directly at the physical asset level (e.g. government controls of mining sites), and by data providers.

In the case of companies, investors access company data primarily through annual reports, either directly or through data providers that aggregate annual report information. The scope of such disclosures is usually regulated. In the EU for example, reporting on non-financial data is regulated by a European Directive on non-financial and diversity information, although the climate-related disclosure requirements in this Directive are relatively under-developed and not standardized.

With regard to climate issues, a number of key indicators are usually not reported by companies, notably the breakdown of capital expenditure by energy technology and the nature of R&D investment. Companies justify this disclosure gap by arguing that it involves propriety information that could affect competitiveness.

Some climate-relevant data is collected by governments directly. Investors can access public data either directly or again through data providers. This data may be relevant both for assessing specific companies (e.g. fuel efficiency of cars by manufacturer) or for benchmarking companies relative to national indicators (e.g. annual electricity generation).

Data providers aggregate (and usually sell) data from physical assets, companies, reporting mechanisms, and public agencies. Beyond that, data providers also provide tertiary performance data, such as qualitative scores, or ESG scores, that are developed using a specific set of data and application of weights.

Both financial and nonfinancial data can be relevant for climate-related investment activities. Regulatory and market standards usually result in financial data that is reported in a standardized fashion (e.g. EBIT, etc.). Non-financial data, on the other hand, is largely non-standardized and thus needs to be harmonized or 'treated', although there are exceptions (e.g. proved oil & gas reserves).

It should be noted that the distinction provided here between financial and non-financial data is not one designed to speak to the materiality of the data itself for financial analysis, but rather a differentiation between 'operational' data and 'financial' data, expressed in monetary terms.

One of the key challenges in the sources of data question relates to the business model of data intermediation and presentation. Thus, as will be outlined later, certain types of data gets linked to financial securities, allowing easy manipulation by portfolio managers, whereas other data only gets linked to companies and thus cannot necessarily easily be linked to financial instruments."

This chapter will first discuss two types of corporate data (carbon footprint and green / brown metrics) and discuss the relative advantages of asset-level data.

5.2 Traditional corporate level data

5.2.1 Carbon footprinting at the company level

The 2° Investing Initiative reviewed the state of the art of carbon footprinting data for financial portfolios in 2013 (2° Investing Initiative (a), 2013), and the number of data providers has continued to grow since then, with a particular focus on listed equity (due to both the size of typical equity portfolios and data availability for listed companies). Further analysis in this field was published jointly with the 2° Investing Initiative, WRI, and UNEP FI (2° Investing Initiative, UNEP-Fi, WRI, 2015) and subsequently by Kepler-Cheuvreux (Kepler-Cheuvreux, 2015).

Carbon footprinting data is arguably the only type of data that enables a relevant comparison of the climate intensity across sectors. Moreover, although there is a significant margin of error for data at an individual security level, this error is relatively low at the portfolio level. Finally, the relative costs of implementing carbon footprinting are relatively low for institutional investors and may be decreasing with time as more data providers are introduced.

5.2.2 Green / brown metrics

Green/Brown metrics are sector-specific indicators distinguishing between climate solutions and climate problems. This category includes two main types of metrics: 1) ratios of exposure to different technologies or business lines and 2) sector-specific energy or emissions intensity/efficiency metrics.

Investors primarily access green / brown exposure metrics through ESG data providers. Data can also be accessed through bespoke databases, though it will generally be more economically efficient for data providers to aggregate and sell such data. Examples of core data include Wood Mackenzie (recently acquired by Verisk Analytics) on the oil, gas, and coal sector, ThomsonReuters and Infrastructure Journal on project finance, and GlobalData for the power sector. Some data is also publicly available; for example, the US Energy Information Administration makes its data available for free.

Green / brown exposure metrics can encompass a range of indicators within different sectors, not all of which are currently available to investors. Key challenges are access to data and the extent to which green / brown categories distinguish between climate impact within categories (e.g. between gas and coal). As the following tables highlight, metrics are currently limited to specific sectors, and cannot be easily aggregated or compared across providers.

Table 4 Overview of green / brown metrics by sector (2° Investing Initiative, UNEP-Fi, WRI, 2015)

	Brown	Green
Oil & Gas & Coal	• Share of high-cost capital expenditure • Share of unconventional (e.g. tar sands, deepwater) oil in production mix	• Share of carbon capture and storage • Share of renewables in R&D and capital expenditure
Power	• Share of high-carbon electricity generation • Est. remaining lifetime of power plants	• Share of renewables in elec. generation, installed capacity, and capital expenditure
Transport	• Average fuel economy of car fleet	• Share of sustainable propulsion technologies in sales
Manufacturing	• Energy and carbon intensities	• Share of zero-carbon manufacturing • Relative investment levels in green manufacturing R&D or deployment
Cross-sector	• Share of oil & gas in sales / revenue • Share of coal in revenues	• Share of 'green' (e.g. low-carbon economy) in sales / revenue

As highlighted previously in a study co-published by the author (2° Investing Initiative, UNEP-Fi, WRI, 2015), "industry classification data, which is used as part of the traditional financial data framework, acts in a similar way to green / brown data, albeit usually at a different (sector) level. In this capacity, it can complement technology-level green / brown data or be used where more granular data is incomplete (e.g. for corporate bonds). Financial databases organize companies based on industry classification codes. Major types include the North American Industry Classification System (NAICS), the Standard Industry Classification (SIC), the Global Industry Classification Standard (GICS), the Industry Classification Benchmark (ICB), the Bloomberg Industry Classification System (BICS), and the UN International Standard Industrial Classification of All Economic Activities (ISIC).

Traditional industry classification systems are usually built based on revenue, which doesn't account for a categorization of non-financial performance. Moreover, their level of granularity is usually relatively low when it comes to emerging sectors, in particular with regard to energy technologies. This is a barrier to using industry classification for climate friendliness assessment. Nevertheless, they are meaningful when looking at high-carbon sectors.

Alternatively, investors can switch from traditional to alternative systems. This switch can relate both to sector allocation guidelines and to a broader tracking of exposure to various sectors. One example is the SASB Industry Classification System (SICS), which categorizes industries based on resource intensity and sustainability innovation potential."

5.3 Beyond company level data – Graduating to asset level data

Economic activity data, or 'climate data', is required to identify a financial actor or markets' alignment with, or exposure to, the economic activity that can be associated with 2°C scenarios and inform on associated financial analysis. It can be used as a reference point in the context of the allocation of macroeconomic scenario data to microeconomic actors. There are a range of different economic data points that can be sourced to define the climate unit of a firm, u^{issuer}, and can be accounted at four levels: the physical asset, business activity (sectorial), the firm, and the market sector. Depending on data availability in the market and the type of analysis desired, different levels may be more or less appropriate (Thomä, Dupré and Hayne, 2018)

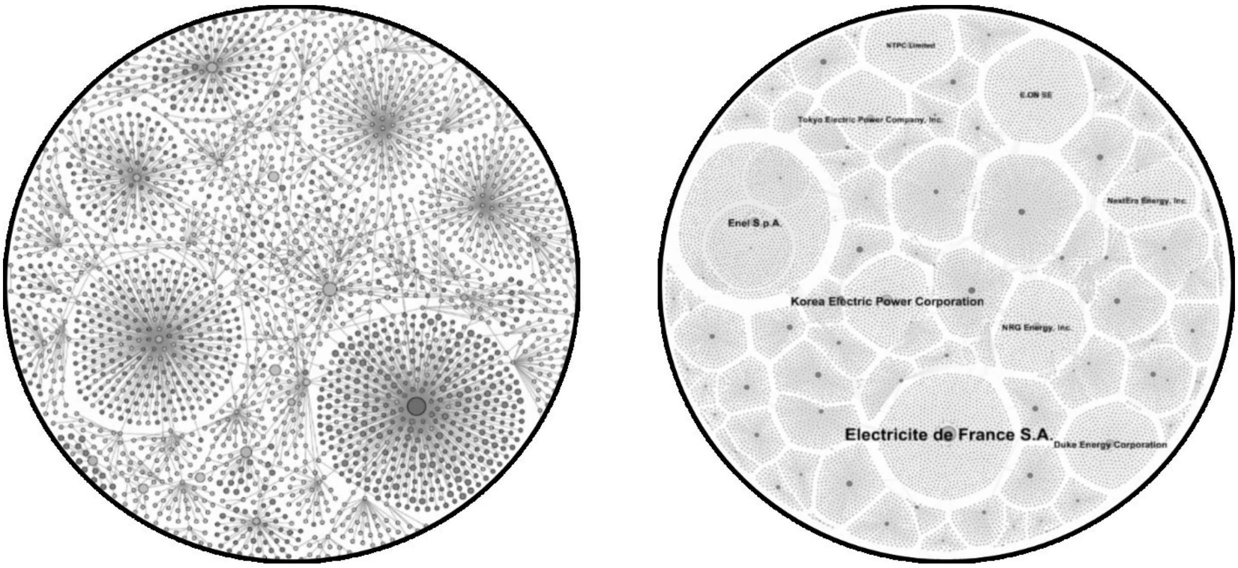
When it comes to sourcing economic activity data, with the exception of R&D, which can only be quantified at the company level, the key underlying data defining a company's activities begin from the individual asset level. Discrimination of individual assets allows for a regional benchmarking of the analysis to regional scenarios (where those exist, e.g. for power production) and a direct link between economic activity by technology and sector to the scenarios. It also enables assessment of granular physical transition risk and policy risks.

This individual asset level data can come through aggregated corporate reporting channels or through asset level databases that collect data from a range of sources, including press releases, regulatory filings, surveys, annual reports, and industry publications (2° Investing Initiative (c), 2017). The actual choice in terms of data sourcing is independent of the application of 2°C scenario alignment analysis, that is to say, both options are in theory acceptable. In practice, however, asset-level data is significantly more suitable. As highlighted above, corporate reporting at the physical asset level is often inconsistent in terms of timeliness of disclosure, accounting principles and coverage in terms of both geography, and type of asset and/or reporting entity (Kepler-Cheuvreux, 2015). This limits the universal applicability of the scenario analysis itself and thus can undermine its role of providing market or global prospectus. On the other hand, asset level database created by market intelligence organizations allow for more comprehensive scenario analysis for typical financial portfolios due to possible standardization and choice of accounting rules, being actively maintained, and often including forward-looking activity (2° Investing Initiative (c), 2017) (Caldecott et al., 2018) .

That is of course not to say that this type of data does not have its shortcomings. Primarily these relate to the lack of transparent formal auditing of the underlying data which leads to different databases have conflicting information on the ownership of a given asset. In addition, the datasets can be limited to particular industrial sectors, and are not necessarily harmonized across different business activities making consolidation for diversified firms or large corporate entities expensive and technically difficult to undertake. The assessment of the quality of the asset level data corporate information has only be undertaken in one study (Glattfelder and Hayne, 2017), and no formal cross evaluation of asset level database has been carried out to date.

The figure below highlights the complexity that this exercise of matching assets with owners can entail. It shows the network of power plant owners across a sample of companies, with each of the individual nodes representing individual companies.

Figure 21 A visualization of power-plant owning companies ownership trees, based on research published by Glattfelder and Hayne (Glattfelder and Hayne, 2017)



The following table summarizes the key pros and cons of asset level data

Table 5 Pros and cons of asset-level data

	PROS	CONS
ASSET LEVEL DATABASES	High degree of global coverage of climate-relevant sectors (80-100%) Allows for application of accounting rules to companies and financial instruments based on user choice	Generally not applicable in the context of broader climate assessments beyond 2°C scenario analysis (e.g. current coverage ~20% of the financial portfolio)

	Provide forward-looking information in many cases	Uncertainty in corporate ownership trees may lead to some errors in the data aggregation process Data is not audited and verified independently Data is not consolidated across industry sectors
COMPANY REPORTING	Audited, verified data Can capture company strategy (e.g. company targets, etc.)	Companies rarely provide a comprehensive overview of their industrial assets, thus limiting assessment, and when an overview is provided, it is generally backwards-looking Aggregated company reporting (e.g. average costs, absolute GHG emissions) generally not directly useful for scenario analysis. Inconsistent accounting rules related to boundaries and data aggregation across entities leads to inconsistent analyses

Nevertheless, asset-level data is the start of the art and the only type of data point that allows, at least currently, for comprehensive, forward-looking analysis of corporate production and investment trends, the basis against which portfolios invested in these corporates can be benchmarked against 2°C scenarios and managed in a framework of optimal diversification, consistent with the vision developed in the first part of the thesis. The next chapter will then explore how such a model can be designed.

6. The 2°C portfolio model in theory

6.1 Overview

This section builds to a large degree on a previous publication of the author (2° Investing Initiative (c), 2016).

“The 2°C portfolio model helps to measure the delta between the economic activity in a financial portfolio and the desired economic activity it should contain in order to be consistent with a 2°C or well-below 2°C world. It does this by quantifying the economic activity on the basis of the economic assets owned or financed by the financial instruments in the portfolio, calculating a relationship between the two based on a set of accounting principles described further above. This exposure of a portfolio is the compared to a desired exposure represented by a ‘2°C benchmark’, which traces the optimal diversification path a portfolio would take under a 2°C transition, calculated based on a combination of economic 2°C scenarios and their adjustment to specific asset classes, investment geographies, and time horizons. Thus, the ‘2°C benchmark’ represents optimal diversification in relation to a time horizon, an economic scenario, an asset class, a portfolio’s geographic exposure, a set of accounting principles, underlying economic data and the scope applied to them, as well as choices on the representation of results in terms of units and scope. The model described further below sets the framework within which each of these aspects can be defined in different ways.

The model involves a number of key features and distinguishing characteristics that are briefly summarized below:

- The model does not pre-define macroeconomic trends or shocks, but rather creates a ‘translation software’ that maps forecasted macroeconomic trends and shocks to financial portfolios. It thus doesn’t rely on developing these economic trends themselves and can be used to test any macroeconomic assumption.

- The model assesses the 2°C alignment of financial portfolios with a 5-year time horizon / forecast period. The time horizon is limited to the time horizon of capital expenditure planning for which data can be tracked at a meaningful level. More long-term assessments are planned as the model gets extended to risk-related indicators, requiring a set of additional assumptions.

- The model assesses the ‘technology exposure’ of portfolios across a range of climate-relevant business segments and sectors. At this stage, it covers fossil fuels, power, and transport (light-passenger duty vehicles, airplanes). Indicators are considered either in ‘aggregate exposure’ terms or ‘trajectory terms’ (i.e. investments, asset additions / retirements, changes in production profiles).
- The model sources, where possible, forward-looking asset-level data for key technologies in order to provide for geography-specific assessments for specific business segments mapped to the company level. It thus bypasses wherever possible backwards-looking, corporate level reporting, although such reporting can be used for validating forward-looking parameters (e.g. GHG emissions).
- The model develops financial market specific, science-based benchmarks that compare portfolio performance not just to existing market benchmarks, but benchmarks associated with decarbonisation pathways.
- The model focuses on assessing specific asset classes, with the assessment at this stage limited to credit instruments (in particular corporate bonds) and equity (in particular listed equity, although it can be applied to private equity).
- Given its emphasis on technologies and climate, the analysis is limited to those parts of the portfolio with direct exposure to the relevant technologies. It thus only covers around 20-30% of the average portfolio in terms of AUM, although around 70-80% of the portfolio’s GHG impacts.”

6.2 Data sources

The translation of economic transition trends into financial markets requires four types of data: i) scenario data, ii) economic activity data, iii) financial market & ownership data and lastly, if trying to measure the trend of a specific financial actor, iv) financial portfolio constituent data. This section will walk through of each these different data needs individually.

6.2.1 Scenario data

Energy transition scenarios detail the potential decarbonization of the global economy. This is done through the use of integrated assessment models of global economies and climate systems that provide potential pathways for global energy production and broader climate-related industrial trends. These pathways are underpinned by projected global macroeconomic trends, modelled climatic response to the associated greenhouse concentration and the potential resultant global warming. This data is published primarily by the Integrated Assessment Modeling Consortium and used to drive projections/pathways of industry production capacity from different technologies under scenarios that represent certain probabilities on maintaining global temperatures with some threshold, such as 2°C. These potential production pathways, in turn, are published by the likes of the International Energy Agency, Greenpeace and industry actors (e.g. Shell, BP), and it is this level of modelling that can inform scenario analysis.

The specific choice of scenario is not fundamental to the framework provided here. Indeed, the framework should be able to process a range of different scenario inputs. What is of crucial importance, however, is that whatever choice of scenario is applied, the unit of accounting within that choice is consistent with the unit of accounting used in the economic activity data that inform the comparison of the financial portfolio to the scenario. Thus, if the analysis is conducting 2°C scenario analysis on production capacity, for example, the scenario units need to be expressed in this way.

As outlined above, the benchmark applied in the model relies on a translation of energy-technology scenarios into benchmarks for financial portfolios. The model by itself does not prescribe specific energy-technology scenarios but allows for a range of scenarios to be used as benchmarks. The choice of which is used can critically influence the results of the assessment, and thus an assessment can be made against both individual scenarios or all available scenarios to show a range of possible decarbonisation pathways.

Scenarios differ in the following elements:

- Scenarios will reflect different levels of ambition regarding the decarbonisation of the economy (e.g. probability of achieving 2°C alignment);
- Scenarios will involve different speeds around which decarbonisation takes place, with some assuming a more accelerated, linear, and short-term adjustments and others assuming more long-term disruption;
- Scenarios have different coverage in terms of geographies assessed, both in terms of absolute coverage and the resolution of geographic specificities;

- Scenarios reflect different progress in certain technologies (e.g. nuclear, carbon capture and storage, etc.);
- Scenarios provide for different time horizons, with some scenarios as short as 5 years and others calculating decarbonisation pathways over several decades.

The indicators extracted from the scenarios to inform the model at this stage are either asset indicators (e.g. installed capacity) or production indicators. In theory, indicators could also be extended to investment indicators, although the lack of annually updated, technology-specific, global investment roadmaps create a barrier to using these as benchmarks. In addition, investment figures are associated with higher levels of uncertainty given the uncertainty both around the technology pathway itself and the costs associated with different technology deployments within these pathways.

Data for the scenario pathways are extracted with a 25-year time horizon. For the 2°C portfolio assessment, the actual assessment is limited to a 5 year time period. Scenario data is extracted for the regions provided by the scenario provider and then aggregated into five regions: Global, OECD, Non-OECD, USA, and Europe. Further detail is possible and can be applied to the model.

Data points from publicly available scenarios usually are presented in 5-year intervals. Missing data is interpolated using a linear function. A function with more degrees of freedom could be applied as an alternative modelling decision to 'smooth-out' the transition between data points.

The extracted data from the scenarios for electric power is installed capacity and CO2 emissions by fuel/technology. The different fuel categories are coal, gas, oil, nuclear, hydropower (large and small-scale), and renewables. Renewables is an aggregated category involving solar PV, CSP, wind power, biofuels, and geothermal. The aggregation decision is a function of reducing the complexity of the results while still maintaining resolution on hydropower given its different level of societal acceptance in some countries.

The extracted data from the scenarios for the automobile sector at this stage is limited to light passenger duty vehicle data by drivetrain. It distinguishes three categories: electric vehicle (which include extended-range electric vehicles), hybrid (which includes plug-in and conventional hybrids), and internal combustion engine (which includes diesel, gasoline/petrol, compressed natural gas, and liquefied petroleum gas vehicles). While fuel cell and other types of drivetrain data are also extracted, the current marginal production does not allow for a meaningful assessment. In addition, where available, fuel efficiency estimates are also extracted that can be integrated into the assessment.

The extracted data from the scenarios for oil & gas are production profiles by region. The extracted data from the scenarios for coal is global coal production. At this stage, the model does not extract data for other sectors.

6.2.2 Economic activity data

As outlined above, for *2°C* scenario alignment analysis, the climate units need to be expressed in the same unit as the scenario itself for comparability. Thus, the data point may either be expressed in production capacity, production, investment / financing, and / or CO_2 / GHG emissions. The choice of indicator among this category is somewhat subjective and involves various trade-offs, summarized the Table below.

Table 6 Pros and cons of different types of economic activity data

	PROS	**CONS**
PRODUCTION CAPACITY (CATEGORIZED BY TECHNOLOGY OR CO_2 INTENSITY INPUT)	In most sectors data point with the highest degree of accessibility and quality; Requires limited to no additional estimates around utilization rates Directly relates to 'supply' investment decisions of companies	Not directly related to financial indicators; May over- or understate climate impact; For some sectors (e.g. cement), lack of technology alternatives does not allow for discrimination of production processes
PRODUCTION	Directly related to financial indicators (revenues, sales) More closely related to climate impact	Requires uncertain estimates around utilization rates Since production relates to 'demand' profile, doesn't necessarily reflect the investment decisions of companies
INVESTMENT	Directly captures capital allocation choices at the investment level	Large variation between the full underlying investment volume and related final deployment capacity Scenarios generally do not express units in investments and where

	The only option for R&D expenditures, since here no other economic activity can be measured	they do, estimates are highly uncertain.
CO_2 / GHG EMISSIONS	Indicator most directly related to climate impact Can be aggregated across sectors if normalized by financial indicator (e.g. revenue, market capitalization) and applied across all sectors	Uncertainty in GHG emissions estimates May not be linked directly to company decisions, since GHG emissions estimates are sometimes determined by external factors (e.g. supply chain); May hide technology diversification and thus exposure to low-carbon / zero-carbon alternatives (e.g. renewables)

Given the balance of pros and cons, the model developed here relies on the production capacity logic, organized either by CO_2 intensity or technology. The reason for this is that it a) minimizes the data uncertainty in the economic activity data, b) can be linked to equivalent units in the scenario that have lower uncertainty than investment levels, and c) reflect the 'supply decisions' that companies control. While this is the choice taken in these methodologies, alternative choices can equally be deployed using related conversion factors, with the exception of the use of production capacity data relating to R&D investment figures, where investment figures need to be mobilized.

The 'transition data' in the model relies, wherever possible, on bottom-up, physical asset-level data. These physical asset level databases are sourced sector-specific. For each sector / technology, they can be sourced from a range of different data providers.

6.3 Model construction

The analysis provided here builds on the models developed in the EU funded Sustainable Energy Investing metrics (SEIM). A variant of these models has been applied by over 200 financial institutions in their portfolio analysis, as well as two financial supervisory authorities and the Swiss government. This section walks through the general principles of the equations used for scenario analysis, starting with basic fundamental equations, the units of measurement, the allocation of units to financial instruments, and the benchmarking process against scenario pathways.

In the course of application with financial institutions, two different approaches materialized, which are summarized in the equations below. It is worth briefly highlighting each in descriptive terms. The first approach suggests measuring the 2°C alignment of a financial portfolio at some future point t relative to what is called here a '2°C benchmark'. This approach is basically an extension of traditional tenets core to modern portfolio theory, where future optimal diversification is measured with regard to not a financial, but a climate-related target. This approach involves measuring the delta of the aggregate portfolio exposure to a climate unit, u^x, with the market exposure under a 2°C transition. The market exposure under a 2°C transition here represents the expected evolution of the defined market, which can be scoped in various ways similar to the application of different traditional benchmarks (e.g. equity market, economy, regional equity market, a set of peer portfolios), under a 2°C transition.

The second approach can be labeled as the 'trajectory approach', where the measurement does not compare absolute exposure at a future point to the absolute exposure of a market benchmark, but rather seeks to compare two rates of change, namely the rate of change in the portfolio with respect to the climate unit, and the necessary rate of change under a 2°C transition.

6.3.1 Portfolio equations

The basic equations governing the two approaches can be summarized by the two equations below for a portfolio, although the concept can also be extended to a firm-level analysis,

Equation 4 $$\mathrm{y} = \frac{u^x}{u^{bench}}$$

Equation 5 $$y^{traj} = \frac{u_t^x - u_{t0}^x}{u_t^{bench} - u_{t0}^{bench}}$$

where u represents a climate unit defined as one of three key climate metrics based on the taxonomy developed by Dupré et al. These three units are either GHG emissions, green / brown metrics (i.e. low-carbon or high-carbon products and services), or qualitative scores, depending on the choice of economic activity and scenario data discussed above. In principle, while the focus here is on financial portfolios, the climate unit can either be calculated at company level (u^{issuer}), individual portfolio level (u^{port}), or a group of portfolios (e.g. the listed equity market in aggregate, u^{market}). In turn, u^{bench} represents the value that u should take to be consistent with a target climate outcome / the scenario. Thus, when applied in conjunction with a 2°C climate goal is designed to reflect a benchmark exposure consistent with the Paris Agreement objective.

The specific configuration of these two fundamental equations will now be broken down in further detail.

6.3.2 Calculating the portfolio's climate unit

The portfolio's climate unit, u^x, can be calculated as follows

Equation 6 $$u^x = \sum_i^f \left(\frac{p_i}{a_i}\frac{u_i^{issuer}}{n}\right)$$

where p is the value of instrument i in a portfolio with a total of f instruments, a is the allocation factor that allocates the economic activity of the instrument i to the portfolio u^{issuer} is the climate unit of the issuer of instrument i, and n is the normalization factor in those cases where the climate unit of the company is normalized in some form.

The logic of the equation can be explained as follows. Defining the climate unit of the portfolio requires allocating the climate units associated with the issuers of the instruments within the portfolio by some fixed rule to the portfolio. This allocation factor is a function of both the value of the issuer's instrument in the portfolio and some factor that determines how that weight should be put into context. One simple factor here is the total weight of the portfolio, basically creating an allocation factor that distributes the climate unit of the issuer to the portfolio as a function of the percentage that the associated instrument represents in the portfolio. The calibration of this allocation factor will be discussed in further detail below.

On the other hand is the climate unit to be allocated. For the sake of completeness, a normalization factor is added, since the climate unit may be normalized in some cases. One simple example where normalization may be relevant is where the portfolio climate unit is meant to represent a weighted GHG emissions intensity of power production for example. In that case, the climate unit of the issuer needs to be total GHG emissions over total power production, where total power production does not actually represent a climate unit, but a normalization factor by which the climate unit is normalized and thus set in relation to another unit (in this case, power production). On the other hand, comparing absolute ownership of renewable power between two portfolios would not require normalization. By extension, the use of this normalization factor is a function of the exact analysis is desired.

6.3.3 Allocation factor for the climate unit to financial instruments

The allocation factor is determined by the analysis' approach, to which here one considers two fundamental types: the balance-sheet approach (a^{bl}) and the portfolio-weighting approach (a^{wt}). Again, it is relevant to first describe the logic of the two before diving into the equations. In simple terms, the balance-sheet approach allocates the climate unit of the instrument of the issuer as a function of how much the portfolio owns of all outstanding instruments of the issuer. This approach can be said to represent a 'responsibility' logic.

As will be outlined in further detail below, the responsibility can be a function of the portfolio ownership in all outstanding instruments in that asset class (e.g. equity ownership) or take a broader view. The portfolio-weight approach allocates climate units based on the share of the instrument in the portfolio, creating a weighted climate unit as a function of the capital that was allocated by the portfolio to different instruments.

The key difference between the approaches being the allocation through portfolio-weighting is defined solely by the construction of the portfolio, while the balance-sheet approach considers the relative volume of each instrument in the portfolio alongside the respective size or value of the firm or asset-class. The equations governing each approach is summarized as

Equation 7 $\quad a^{bl} = \sum_i^g p_i$

Equation 8 $\quad a^{wt} = \sum_i^h \sum_i^k p_i$

where g, represents the number of instruments in one asset class, and h represents the total number of asset classes issued by the firm or held in the portfolio under evaluation.

For example, in the case of assessing equity with the balance-sheet approach, a^{bl} can represent the outstanding equity of firm i, being the sum of all equity over each equity instrument, g, issued by the issuing firm of instrument i. Thus p_i/a_i^{bl} is then equal to the ownership share the portfolio has in the issuer, and the product with u_i^{issuer} represents ownership of the climate unit of the issuer of instrument i. Finally, u^{port} then represents the total portfolio ownership. The concept of the issuer can also be extended to all financial instruments, such that a is equal to the enterprise value of the firm, or another subset of outstanding assets (e.g. long-term debt plus equity).

The key challenge with this allocation factor is that when it is extended outside of equity, where ownership percentages can be calculated independent of financial asset price movements, price biases can be introduced related to the movement in asset prices, which in turn introduce fluctuations in the metric that are not necessarily correlated to changes in capital expenditure or production plans. This can follow on to introduce bias and uncertainty around the required action of the portfolio owner or manager. In the case of enterprise value, this fluctuation is driven by changes in relative market prices (Thomä et al. 2018).

The alternative portfolio-weighting approach, a^{wt},calculates relative intensities of the portfolio's exposures to different products and services, and rather than the desire to measure absolute ownership. As the allocation is based off the relative value each instrument in the portfolio alone, portfolios across asset classes can be jointly examined. Here, only one type of option can be considered, namely the overall size of the portfolio.

It should be noted that intuitively, the absolute units calculated using the portfolio-weight approach may not be meaningful. For example, a portfolio that exclusively owns an oil & gas issuer will be allocated 100% of the climate unit of said issuer, even if the portfolio size is only $100. At the same time, sectoral weighting approaches described in further detail below can contextualize the figure with a benchmark to highlight the relative intensity of the exposure. Equally, in the case of the power sector, relative renewable power intensities of different companies can be weighted using the portfolio-weight approach to highlight the capital allocation choices of the portfolio manager.

In summary, the framework described until this point looks at how to calculate the climate unit of the portfolio. The next section will discuss how this climate unit can be benchmarked in the context of 2°C scenario analysis.

6.3.4 The benchmark

The benchmark, u_t^{bench}, has to be expressed in the same climate unit as u_t^x, and is calculated as follows

Equation 9 $\quad u_t^{bench} = s + e_t$

where s represents the starting point of the benchmark when $t = 0$, and e_t the decarbonization pathway, i.e. expected change to s at time t in order to be consistent with the 2°C climate goal. s can be calculated in three different ways, depending on the desired normalization of the portfolio, shown below

Equation 10 $$s^p = \frac{\sum_i^f p_{t0}}{\sum_i^j p_{t0}^{market}} u_{t0}^{market}$$

where j is the number of instruments in the market,

Equation 11 $$s^u = \frac{\sum_i^k u_{t0}^x}{\sum_i^l u_{t0}^{market}} u_{t0}^{market,}$$

where u_{t0}^{port} and u_{t0}^{market} is the initial aggregated climate unit for the portfolio and market calculated through Equation (3) respectively, which is summed over the number of each technology represented in the market, k, and the portfolio, l,

Equation 12 $$s^{sec} = \frac{\sum_i^m p_{t0}}{\sum_i^n p_{t0}}$$

where m is the number of instruments in the portfolio from issuers classified under a specific business activity/sector, with a n the number of instruments from all issuers classified under that same specific business activity/sector within the market.

While all three options can be applied, the choice between one or another relates to both the sector and the objective of the analysis. Equation (7) calculates whether the portfolio over- or under-weights a climate unit in absolute terms, independent of the exposures to other climate units. It may thus be more relevant for sectors and products where the scenario itself makes a comment on the evolution of the business activity itself. For example, in the case of fossil fuels (oil, gas & coal production), 2°C scenario generally suggest a decline of absolute production capacity over time, and thus a decline of the value of a portfolio or firm derived from that sector, and calls for a production intensity-based metric,

As in illustrative example, consider the application of Equation (7) for a portfolio with a portion of the investment in equity from the coal sector, and it is to be evaluated using the balance-sheet approach with no differentiation on the type of coal produced. In this case u^{market} calculated via Equation (3) in conjunction with Equation (4) would yield the total production of coal from all firms in the market. s^p would then be the production of coal allocated to the portfolio at the initial point in time based on the current intensity of coal production of the equity market. At this initial point in time, this allocation would be synonymous with comparing the portfolio to a completely diversified equity portfolio, owning the same portion of coal production per asset under management, as the equity market as a whole.

For sectors where the evolution of the business activity is considered 'neutral', and the modelling pathway provides comment on the different technologies and production processes within the sector, considering the weight of climate units in the sector may be more relevant, i.e. through Equation (8). For example, in the case of the power and automobile sector, while the different scenarios assume different aggregate levels of production capacity over time, the key driver of the scenario is the switch from high-carbon to low-carbon fuels in the case of the power sector, and the switch from high-carbon to low-carbon powertrains in the case of the automobile sector. In this environment, it may be relevant not just to understand how high the exposures of the renewable power generation to total electric power, but also the weight of renewables to coal-fired power in the portfolio.

As an illustrative example, consider the application of Equation (8) for a portfolio with a portion of the investment in equity from the power sector, and it is to be evaluated using the balance-sheet approach. In this case u^{market} calculated via Equation (3) in conjunction with Equation (4) would yield the total production capacity for each of the power generating technologies represented in the equity market's power sector. s^{u} would then be the production of each of these technologies allocated to the portfolio at the initial point in time, based on the share of the power market the equity portfolio owned at time t_0.

The choice for s^{sec}, given that it is a rougher sector proxy, appears as a second-best solution where the other two options cannot be applied for technical reasons without creating biases, for example in the case of calculating a starting point for the fossil fuel production capacity in corporate bonds portfolios when applying the portfolio-weight approach.

6.3.5 The dearbonization pathway

To calculate the required change to the benchmark, e_t is defined as follows

Equation 13 $$e_t = \Delta u_t^{scenario} \frac{u_{t0}^{x}}{u_{t0}^{market}} c$$

Where

Equation 14 $\Delta u_t^{scenario} = \frac{u_t^{scenario} - u_{t0}^{scenario}}{u_{t0}^{scenario}}$

where $u_t^{scenario}$ represents the economy-wide climate unit (for example, production capacity associated with a specific product or service, e.g. renewable power capacity) as prescribed by the decarbonization scenario, and c is a constant to describe any adjustment of the market share over time. This could be important in business sectors where market share between economic agents is predicted to change over time. For example, the case of renewable power generation, where in some regions household owned power capacity has been broaching on the utility power market due to the differentiated responses of both participants to certain government incentives. In this case c_t could be used to account for the continuation of historical trends, and explicitly in this example, account for the reduction of the listed utility power overall market share of total renewable power.

The analysis is somewhat complicated by the fact that for low-carbon technologies it may be relevant to disentangle the market share in the technology and the market share in the business activity more generally. Thus, if a utility, for example, has 10 GW of electric power capacity, but zero electric power, simply taking the market share in renewable power (in this case, zero) would suggest that such a utility would not be expected to build out renewables. This is prima facie absurd since such a strategy would allocate full responsibility for capacity additions to historical leaders and absolve historical laggards (not to mention imply a decline in overall market share over time). On the other hand, an electric utility that owns 10 GW of electric power, but no coal-fired power would not be in a position to retire any coal-fired power. This dichotomy between high-carbon and low-carbon technologies requires a calibration of the model to reflect this distinction.

To resolve this tension, the model controls for whether the climate unit, u^x, is associated with a high-carbon or low-carbon product or service through an extension of equation (10) to equation (12) below

Equation 15 $e_t = \Delta u_t^{scenario} \frac{f(d, u_{t0}^x)}{f(d, u_{t0}^{market})} c$

Where

Equation 16 $f(d, u_{t0}^x) = \frac{(d-1)}{-2} \left(u_{t0}^{x,sector} - u_{t0}^x\right) + u_{t0}^x$

And

Equation 17 $f\left(d, u_{t0}^{market}\right) = \frac{(d-1)}{-2}\left(u_{t0}^{market,sector} - u_{t0}^{market}\right) + u_{t0}^{market}$

where $u_t^{x,sector}$ and $u_t^{market,sector}$ represent the total volume of u_t^x and u_t^{market} respectively, across all products and services in one business activity for the portfolio and the market (e.g. the sum total production capacity, in MW, across all types of power-generating assets – renewables, coal, gas, etc.), and d is a dummy value which takes the value 1 if u is associated with a high-carbon product or service and -1 if u^x is associated with a low-carbon product or service.

The core modelling challenge associated with each type of assessment is mapping macroeconomic trends and shocks to financial portfolios and companies. The model uses a simple 'fair share' assumption to map these trends to companies and financial portfolios. This fair share assumption stipulates that economic impacts are mapped to financial portfolios and underlying companies based on the market share these portfolios and companies have in the technology or market that affected by this impact.

The future market share is calculated depending on whether the production profile is set to decrease or increase in the next 25 years according to the macroeconomic trend. If the production is meant to increase, the fair share is calculated based on the total market share of the product (e.g. installed capacity, etc.). This approach is called the 'market fair share'. If the production is meant to decrease, the fair share is calculated based on the total market share of the specific fuel / technology (e.g. coal production, coal installed power capacity). This approach is called the 'technology fair share'. This distinction was chosen since applying market fair share to declining technologies can yield negative results eventually (since the market share could be higher than the technology fair share) and because portfolios that have 'lagged' production increases in the past shouldn't be assumed to do so in the future. In theory, the model could apply the technology fair share for both increasing and decreasing technologies, a choice not made in the current iteration.

The use of the fair share approach could be contested since it ignores important market realities that will dictate how each individual company performs under different macro scenarios. Alternative approaches involve bottom-up assessments of each individual company. While this is technically feasible, it is much more expensive and technically complex. An alternative option for oil and gas companies is to use cost curves to map impacts to low-cost and high-cost producers. The challenge with this approach is both the quality of the data and the logic of assuming costs are the primary drivers. Nevertheless, such a cost curve approach is likely to be more accurate than a simple, fair share assumption and can be applied to scale with given datasets where they include production cost information. It would, however, be limited to fossil fuel companies in its application.

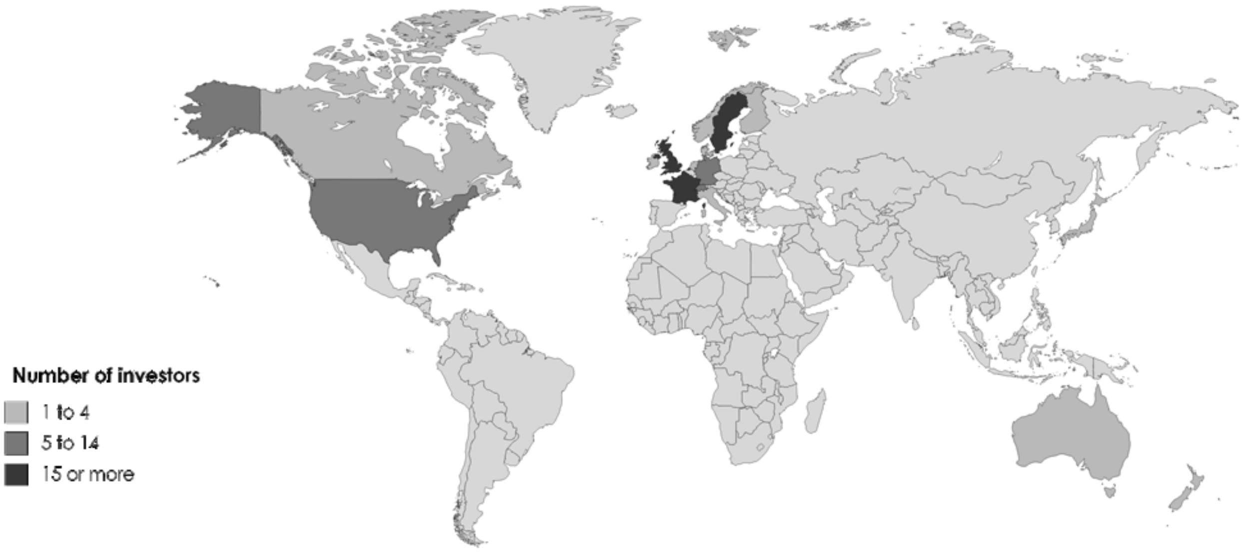
7. The 2°C portfolio model in practice

7.1 Scope of application

Since launching the model, over 250 investors across 16 countries have committed to testing their listed equity portfolios, testing approximately $350 billion USD of equity, as well as 20 investment products. Including index assessment, these tests have covered over 80% of developed markets stock markets and the two investors that won the 2016 2° invest awards both applied the model (AXA Group (a), 2017), (TPT Retirement Scheme, 2017). To put this number into context, around 125 investors have signed the Montreal pledge, and 25 have joined the Portfolio Decarbonization Coalition.

The following sections will discuss various three applications: the Swiss government pilot, an application with financial supervisory authority, and an analysis of a large universe of funds.

Figure 22 Distribution of road-testers by country



7.2 Case study: Application by the Swiss government

In Switzerland, the Swiss State Secretariat for International Financial Matters (SIF) and the Swiss Federal Office for the Environment (FOEN), together with the 2° Investing Initiative, initiated a voluntary pilot project in 2017 to analyze the alignment of Swiss pension funds and insurance companies with the Paris Agreement. As part of this pilot, 79 Swiss pension funds and insurance companies, representing around two-thirds of the market (measured in the share of assets under management of the sector) participated. The project limited its analysis to the investor's listed equity and corporate bonds portfolios. The project involved a meta-analysis for the Swiss government and tailored individual reports for the participating investors.

In terms of data sources, the International Energy Agency scenarios were chosen, notably Energy Technology Perspectives (ETP) for the transport and industrial sectors (International Energy Agency (b), 2016), and the World Energy Outlook (WEO) for the fossil fuel and electric power sector (International Energy Agency (a), 2016). Since IEA data is presented in 5-year intervals, data is interpolated using a linear function where required.

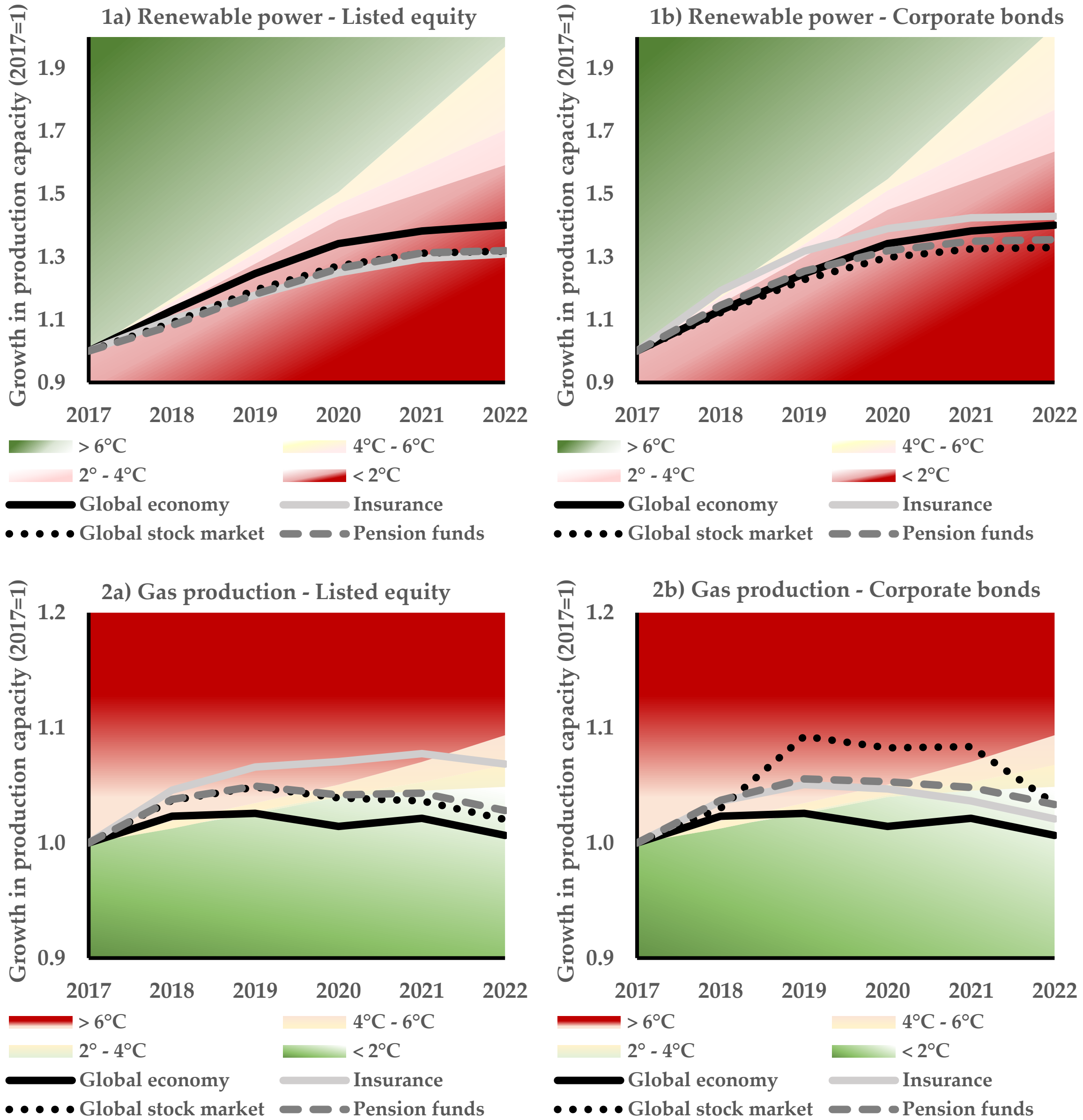
The value of the financial instruments in individual funds and in the listed equity market was taken from Bloomberg with data current as of 31/12/2016. Bloomberg is also the data source that allows for a definition of the market size. The total listed equity market size is derived from Bloomberg data. Crucially, the listed equity market portfolio only includes the free-float share of a company's equity value. This is done to distinguish the investable universe (free-float) and by extension derive a benchmark for the investable universe, rather than the economy as a whole. There are a couple of implications worth highlighting notably that the total climate units in the listed equity market or corporate bonds market are not equal to the total climate units in the economy (given household ownership and ownership by companies that don't issue financial instruments). One concrete implication in practice is that the renewables unit weight in total power is lower in listed equity markets than in the economy since the economy also includes households, which have a renewable power 'bias' relative to power assets owned by companies.

In the model calibration, p_t is always fixed – even if instruments mature at point $t < 5$, at $t = 0$ in order to provide for a consistent analysis. This assumption can of course be adjusted such that p_5 is considered, if desired. The underlying choice will then inform the data needs from Bloomberg and the portfolios.

The meta-analysis applied the trajectory exposure approach highlighted above (Equation 2), focusing on an analysis of the rate of change. In applying the trajectory exposure approach, it looked at absolute changes in production capacity across the energy, power, and automobile sector as the three sectors with the most significant climate impact in Swiss pension funds and insurance companies listed equity and corporate bonds portfolios. Climate units in the portfolios of Swiss pension funds and insurance companies were allocated using the portfolio-weight approach for corporate bonds and the balance-sheet approach (based on equity ownership for listed equity). The choice of two different allocation rules for different asset classes was based on the following reasoning: Given that the objective of the analysis was to identify a responsibility as a point of departure for climate impact, using the balance-sheet approach appeared as the more appropriate allocation rule in general. However, the price and financing biases in corporate bonds markets make this approach somewhat unwieldy and potentially subject to significant biases, as outlined above. As a result, the preferred allocation rule was applied where possible, with the resorting to second-best for corporate bonds. No normalization factors were considered, with each technology and production capacity estimate treated individually.

The figure below shows the results for renewable power and gas production. It is relevant to note here that the results are not represented as percentages but as line charts. Relating this to the equations discussed in the previous section, the Equation (2) can be traced here in terms of comparing the start and end point of each line in the chart to the start and end point of the demarcation line between the green and yellow space, the difference representing the misalignment with the 2°C scenario as expressed in the trajectory approach.

Figure 23 The alignment of Swiss pension funds and insurance companies listed equity and corporate bonds portfolios with the 2°C scenario across renewable power and gas production (2° Investing Initiative (b), 2017)



While the Swiss government focused their analysis on the trajectory exposure, Swiss investors were provided with the results for Equation (4) in their individual reports. Here, the same allocation rules were chosen as for the trajectory approach.

In order to create a consistent scale where outcomes larger than 1 always signify a positive exposure and outcomes smaller than 1 always signify a shortfall, a dummy variable d can be added to the equation which takes the value 1 when u accounts a high-carbon product or service and -1 when u is associated with a low-carbon or zero-carbon product or service. This variable however simply helps to homogenize the result in a way that is more easily understandable for users and is not core to the equation, in particular where the result is expressed in GHG emissions, where the low-carbon / high-carbon distinction does not exist. Adding this factor complicates the Equation (4-5) somewhat, but ensures more intuitive results, such that

$$(15) \qquad y_t^{trajnorm} = (1+d) - d\,\frac{\Delta u_t^{port}}{u_t^{bench}}\{u_t^{port} \leq 2u_t^{bench}\}$$

$$(16) \qquad y_t^{absnorm} = (1+d) - d\,\frac{u_t^{port}}{u_t^{bench}}\{u_t^{port} \leq 2u_t^{bench}\}$$

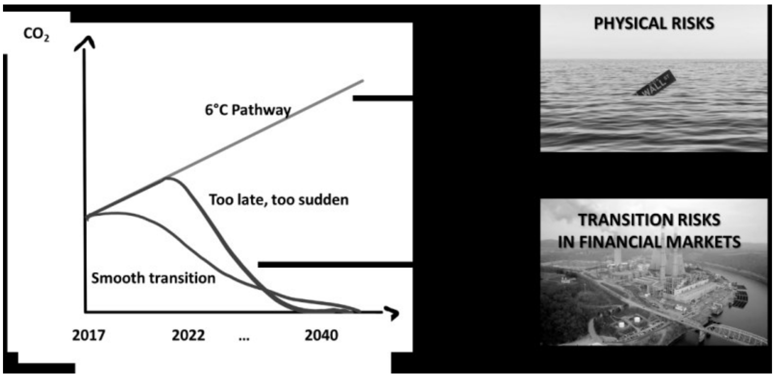
The new equation added the dummy variable and turned the equation into an absolute value equation to avoid negative results, as well as range constraints to avoid the dummy variable influencing the underlying results. The range constraint caps the value of u_{t+n}^{port} such that it doesn't exceed $2u_{t+n}^{bench}$. The constraint limits the results to $0 \leq y_{t+n} \leq 2$, allowing for a consistent and intuitive explanatory power of the results, albeit at the expense of hiding outliers captured in Equation (5).

7.3 Case study: Application by a financial supervisory authority

The application described above in the case of the Swiss pilot project was motivated from the perspective of measuring the alignment of financial flows with the Paris Agreement. An alternative application is that explored by financial supervisory authorities seeking to conduct 2°C scenario analysis more from a risk perspective. The logic motivating such an analysis relates to two types of research questions relevant from the perspective of a financial supervisory authority. The first question is the extent to which the misalignment of financial flows with climate goals may create future financial volatility should climate policies and market trends adjust. Tracking the investment and production plans in financial markets (and portfolios) helps to inform on this question and allow financial supervisory authorities to potentially anticipate and where appropriate explore ways to respond to future volatility. The approach highlighted in the previous section explored by the Swiss government incidentally addresses exactly this question.

The figure below highlights the research question of trajectory exposure, for which the model has been developed and which reflects the research question of a financial supervisory authority.

Figure 24 Stylized representation of physical and transition risk (2° Investing Initiative (d), 2017)



At the same time, there is a second question that derives from this issue, namely the scale of exposure should such risks materialize. This second question requires an alternative approach than the modelling calibration applied in the Swiss project across the range of modelling choices described above. The application described here is that of one pioneered by one financial supervisory authority in Europe in the context of conducting 2°C scenario analysis of their regulated entities, notably focusing on insurance companies.

The pilot project in question used the portfolio data of insurance companies that they regulate. European supervisors have been put in a capacity to analyze the insurance data following the implementation of the Solvency II Directive, which among other things mandates the reporting of the portfolio' constituent information of insurance companies to their financial supervisors. Tapping into this data allowed the financial supervisor to conduct the 2°C scenario analysis described above.

Following the analysis of financial flows, the financial supervisory authority then posed a second question, namely the share of the insurance companies' financial portfolio that may potentially be exposed to financial disruption – and comparing that share to the expected exposure under a 2°C benchmark. This approach built on the same type of data (economic activity data, IEA scenario, Bloomberg financial data) describe above. Instead of representing the results in terms of percentage, the climate unit of the portfolio was directly compared – in absolute terms – to the climate unit of the benchmark.

The application concretely involved the following application of the model: The climate unit was allocated to the portfolio based on the portfolio-weight approach. Climate units were normalized such that the climate unit of an electric utility was derived by taking the percentage power share by fuel source. For example, the climate unit, in this case, would be installed renewable power capacity, with the normalization unit equivalent total installed power capacity of the utility. For oil & gas, oil production capacity was normalized overall energy production of the company (oil and gas).

This allowed for the breakdown of the portfolio into 'high-carbon' and 'low-carbon' shares, where a 1% exposure to a utility (portfolio-weight) would then, for example, be converted into a 0.5% renewable exposure and 0.5% coal power exposure in the case where the utility behind the 1% exposure had a fuel mix evenly split between coal and renewables. This approach seeks to create a proxy to isolate the part of the exposure that was exposed to the transition to a low-carbon economy generally and the parts of the portfolio that were exposed to such a transition on the high-carbon side.

The benchmark was calculated on the same principle, seeking to quantify whether the exposure of the regulated insurance companies exceeded that of the market and – more specifically – the expected future exposure of the market under a 2°C transition.

The approach provided a framework to contextualize the potential risks should future economic disruption associated with a more shock-like adjustment to a 2°C transition following continued investment in business as usual translate into financial risks. The results can be compared then to exposures typically identified for example in stress-test shocks for listed equity markets or other asset classes. At the time of writing, the final results have not been published, although publication is planned in Q2 2018. Illustrative results can thus not be presented here. Equally, the discussion of the modelling framework shows that the general modelling framework developed in Section 3 can be applied both for two very different use cases (alignment of financial flows vs exposure to transition risks) and using different and use-specific articulations.

While it is important to highlight that different use cases also imply low comparability between the results of the two different pilot applications, they demonstrate the power of a common framework that allows different actors to speak the same language when modelling and thinking about 2°C scenario analysis. They also highlight that conscious accounting choices are not just a function of artificial accounting choices, but directly linked to the question being explored in the analysis. For example, the portfolio-weight approach was taken as the more appropriate approach choice for the financial supervisors, versus the balance-sheet approach chosen by the Swiss government.

7.4 Case study: Analysis of funds

This chapter presents data analysis published by the author and the 2° Investing Initiative and the University of Zurich (2° Investing Initiative, University of Zurich, 2018). It is based on an analysis of the largest funds across 13 jurisdictions, taken from the Morningstar database.

The following table provides an overview of the capital expenditure alignment of the aggregated funds per jurisdiction with a 2°C pathway in 2022. The values in the table depict the exposure of the funds capital expenditure plans compared to 2°C compatible capital expenditure plans, using the trajectory exposure approach (Equation 4). It can be seen that the capital expenditure plans of the funds in the automotive sector are far off the targets for all jurisdiction (except for Brazil, which is not invested into car manufacturers according to the available fund data). However, there are still significant differences between the jurisdictions.

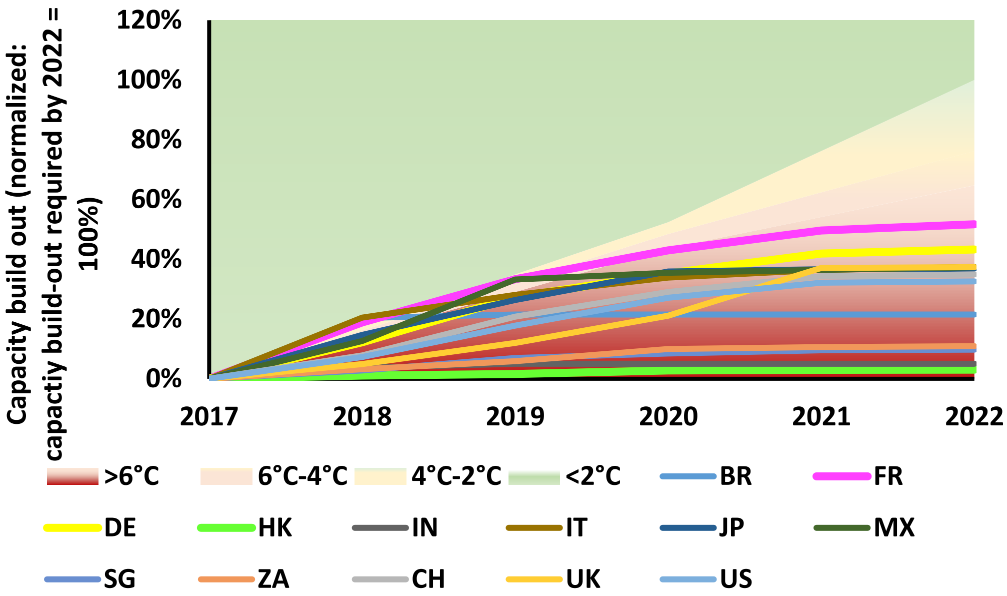
The capital expenditure plans of the funds in the fossil fuel sector are generally aligned with a 2°C pathway. On the other hand, the results in the power sector show a gap in renewable capacity build-out plans for all jurisdictions as well as a misalignment of the coal build-out/retirement plans with the 2°C target.

Table 7 : Overview of 2°C alignment (2° Investing Initiative, University of Zurich, 2018)

Fund domicile	**Automotive**		**Fossil Fuels**		**Power Capacity**	
	Electric	**ICE**	**Gas**	**Oil**	**Coal**	**Renewables**
Brazil			27%	18%	12%	-49%
France	-79%	15%	3%	4%	9%	-16%
Germany	-69%	16%	7%	4%	21%	-19%
Hong Kong	-92%	24%	-8%	-3%	1%	-75%
India	-61%	30%	-27%	-6%	16%	-68%
Italy	-88%	17%	15%	4%	12%	-25%
Japan	-91%	16%	-4%	2%	24%	-26%
Mexico	-92%	23%	0%	6%	13%	-28%
Singapore	-74%	50%	-6%	3%	9%	-50%
South Africa	-91%	26%	-20%	-14%	7%	-25%
Switzerland	-80%	18%	-1%	4%	20%	-33%
United Kingdom	-83%	18%	4%	4%	13%	-26%
United States	-51%	15%	-5%	2%	24%	-33%

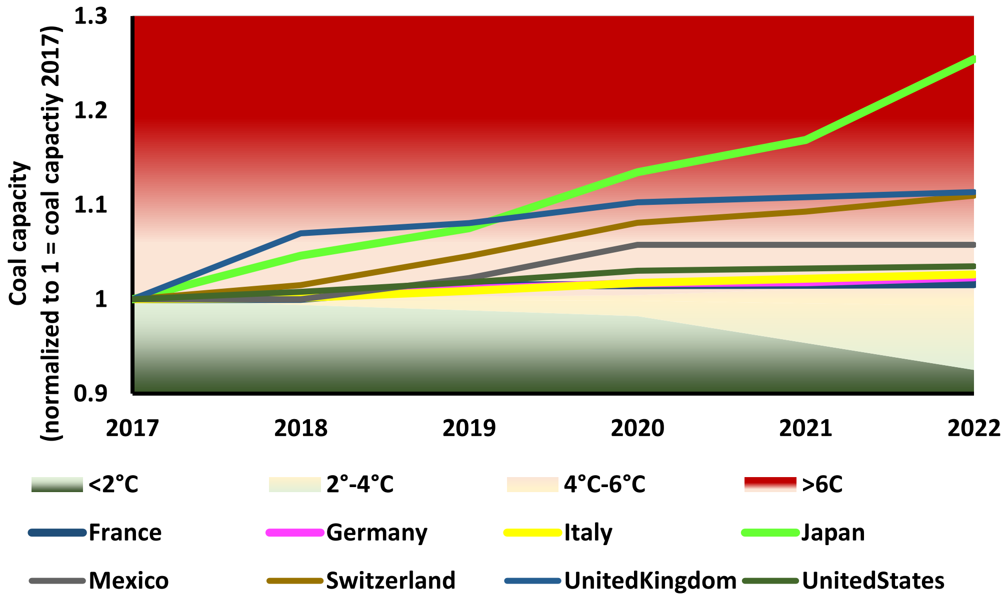
The figure below shows the renewable build out planned by the fund (i.e. the underlying companies the funds are invested in) compared to the 2°C, 4°C and 6°C scenario of the IEA based on the trajectory exposure developed earlier.

Figure 25 Funds renewable power capacity addition plans relative to the 2°C scenario (2° Investing Initiative, University of Zurich, 2018)



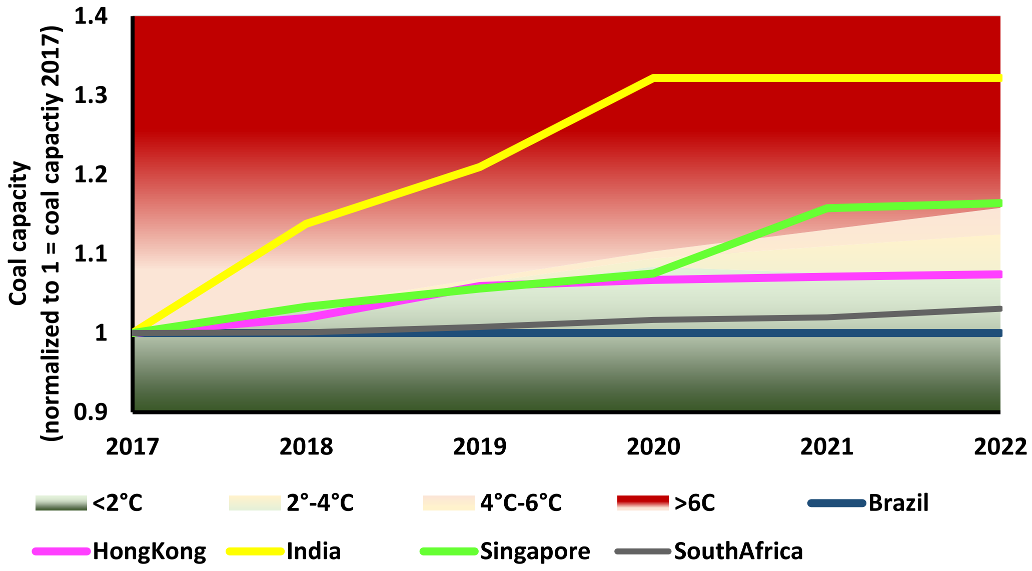
The analysis of coal power capacity expenditure plans for OECD countries shows that most OECD countries are on a 4°C pathway with regards to their capacity additions, shown in the figure below.

Figure 26 OECD domiciled funds coa power capacity additions plans relative to the 2°C scenario (2° Investing Initiative, University of Zurich, 2018)



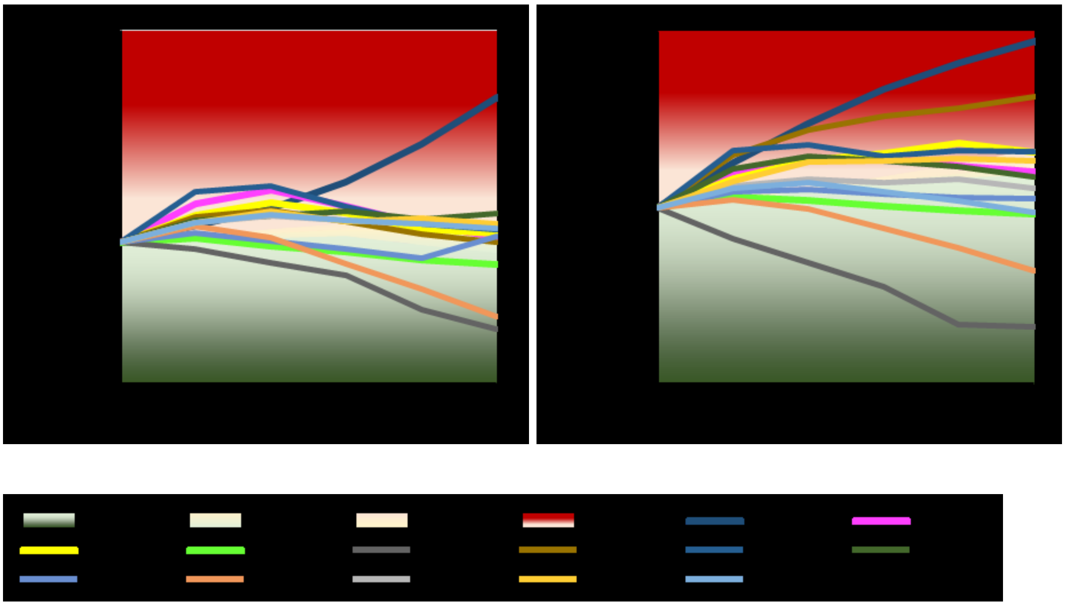
The capital expenditure plans of funds domiciled in non-OECD countries are outperforming the funds in the OECD, mainly due to the higher allowance of coal capacity for those regions in the scenarios.

Figure 27 Non-OECD domiciled funds coal power capacity additions plans relative to the 2°C scenario (2° Investing Initiative, University of Zurich, 2018)



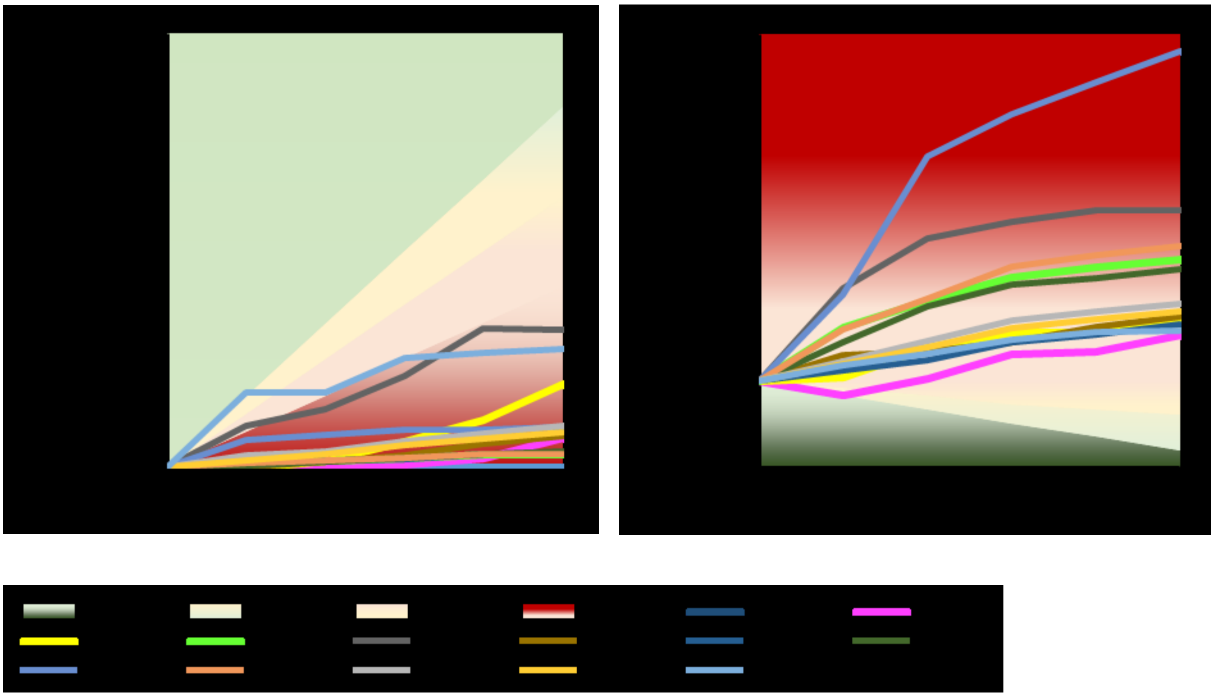
In the fossil fuel sector, the funds capital expenditure plans are roughly on a 2°C pathway as shown in the table.

Figure 28 Funds oil and gas production plans relative to the 2°C scenario (2° Investing Initiative, University of Zurich, 2018)



The climate alignment of funds capital expenditure plans in the automotive sector is the lowest among the three analysed sectors. Most funds follow a 4°C to >6°C pathway with regards to their production plans. The figure below provides the scenario analysis of the funds' electric vehicle capital expenditures. The ICE capital expenditure plans, also depicted below on the right side, are slightly more aligned with the international climate goals.

Figure 29 Funds electric and internal combustion engine vehicle production plans relative to scenarios (2° Investing Initiative, University of Zurich, 2018)

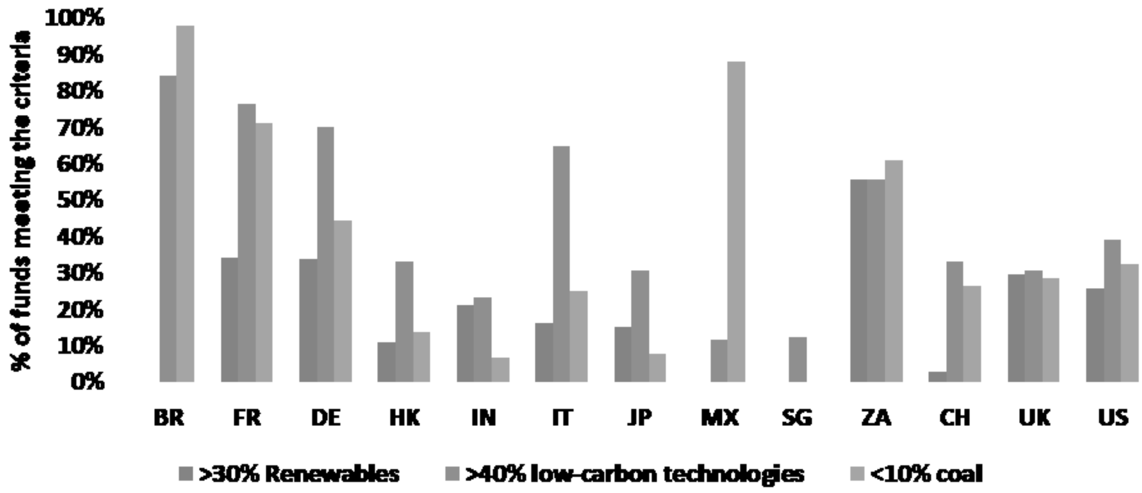


Among the analysed funds there are several funds that meet climate friendly criterion in the power sector. The criterions the funds got tested against are:

a) To have at least 30% of the total power capacity in 2022 within renewable technologies, i.e. wind, solar, tidal, geothermal and biomass
b) To have at least 40% of the total power capacity in 2022 within low-carbon technologies, i.e. renewables plus hydro and nuclear capacity
c) To have less than 10% of the total power capacity in 2022 coming from coal capacity

The figure below presents the percentage of funds among all tested funds that meet these criterions. It can be seen that for each criterion there exist funds in the investible universe in almost all countries.

Figure 30 Low-carbon options in the power sector – funds that meet climate-friendly criteria by 2022 (2° Investing Initiative, University of Zurich, 2018)

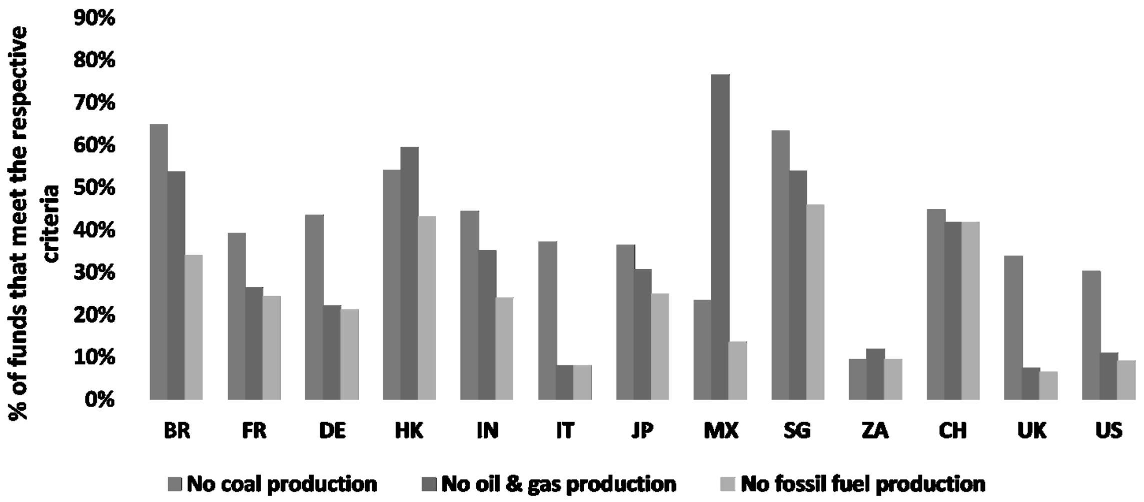


Even more funds among all analysed funds meet climate-friendly criterions in the fossil fuel sector. The criterions the funds got tested against are:

a) To not have any coal production in 2022
b) To not have any oil and gas production in 2022
c) To not have any fossil fuel production in 2022 at all

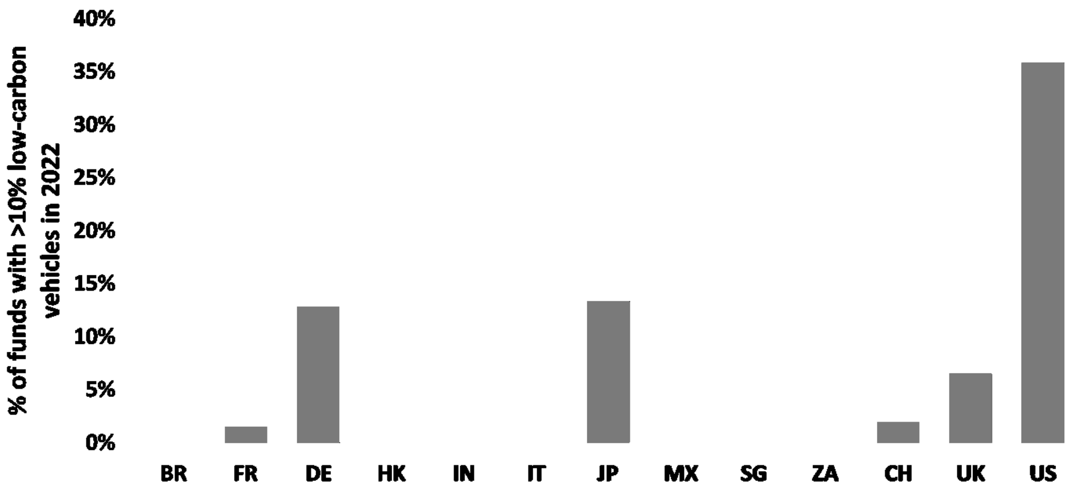
The figure below presents the percentage of funds among all tested funds that meet these criterions. In every country tested in this report there exist funds that meet all three criterions, i.e. that meet criterion c. Thus "fossil free" investment options exist in every jurisdiction.

Figure 31 Low-carbon options in the fossil fuel sector (2° Investing Initiative, University of Zurich, 2018)



For the automotive sector, the funds are exclusively tested if they have ">10% low-carbon, i.e. hybrid and electric, vehicle production in 2022". The figure below shows that both only a few funds meet this criterion.

Figure 32 Low-carbon options in the automotive sector



7.5 Feedback on the model

This section builds on a previous publication by the author (2° Investing Initiative (b), 2016) as well as additional feedback collected since then.

As part of the road-test, feedback was collected via bilateral interviews from over 30 investors, and as part of an anonymous survey involving a sample of 27 investors. Feedback was also collected from a number of external stakeholders including universities, think tanks, and policymakers. This section summarizes the feedback from this process, linking qualitative and quantitative feedback. Since the survey was done anonymously, a chance of sampling bias in the results cannot be excluded.

An online survey (Google Form) was distributed to investors that had tested the model. The survey was administered from August 2016 to July 2017 with 27 responses from institutions that had applied the model on their portfolio. Annex 1 summarizes the survey questions administered in the context of this process.

Out of the 27 institutional investors that responded to the survey, 15 were asset managers and 7 pension funds, with the other respondents spread out among sovereign wealth funds (1), insurance (12), management of an exchange-traded fund (1), and a bank (1). 23 of the respondents were based in Europe, 3 in North America, and one outside of Europe and North America.

Out of the 27 respondents, 12 found the model to be equally relevant and 11 considered the model more relevant. 2 respondents suggested the model is less relevant and 1 respondent suggested that “Neither assessments are relevant”. Thus, out of the 25 investors that considered climate assessments relevant, roughly 44% found the infrastructure developed in this thesis more relevant, and 48% equally relevant.

Perhaps more important, 18 of the 27 respondents suggested that it is likely or highly likely that they would use this type of assessment in their investment decisions or shareholder engagement process.

Out of the 8 respondents that suggested it would be not likely or highly unlikely, 5 responded that they would be likely or very likely to use the tool if was made available on a financial database platform, suggesting that in total 24 out of the 27 respondents (89%) responded that they would likely or very likely use the tool once made easily available.

Out of the three investors who said they would not apply the tool, one commented that this was a function of them only using external mandates and thus considering the model more as a 'check', rather than a tool proper. One of the other investors that said they were unlikely to use it still considered it "more relevant" than existing assessments.

The following provides anonymous quotes as to the qualitative feedback collected in this survey process:

> "We found the assessment to be very useful for us in understanding how our portfolio stands relative to the 2 degree benchmark. However, as yet we have not gone so far as to integrate the results into the investment process. That is a hugely significant step for us and not one that would be undertaken lightly."

> "We have used it because it is said to be the most relevant tool in the field at the moment and we will wait for it to expand to emerging markets and different asset classes." (*NB: The road-test with this investor was conducted exclusively on developed markets listed equity portfolios, explaining the feedback.)*

> "Used it as pilot at this stage. Would like to use it more systematically in the future, for which integration within financial data platform would be very helpful."

> "We have only external, and active asset management. Therefore, we use the analysis more as a check than a tool for stock selection. But I think the analysis could be of great help for AOs and AMs that are not used to thinking about carbon risk."

> "We plan to use the analysis in reporting our climate performance, and in our design of climate related targets."

> "An excellent initiative which deserves wide adoption and engagement to allow users to zone in on the risks of misalignments at a company level"

> "Very useful analysis and looking at an aspect of carbon risk that to date remains relatively under-studied."

> "This is a great initiative that clearly provides useful information that we did not have access to so far. Keep on the great work with your planned expansion to other asset classes and countries."

> "An excellent initiative which deserves wide adoption and engagement to allow users to zone in on the risks of misalignments at a company level"

In terms of the biggest flaws, excluding feedback related to the limited scope of the road-test, which doesn't technically speak to the model, the biggest flaw highlighted in the survey as well as in the qualitative feedback discussions was the complexity of the model. The following quotes highlight this:

> "The methodology was not simple to understand and difficult to explain to colleagues. I had to repeatedly stress that comparison related to the % share of capacity/production represented by our portfolio. An example calculation (high level) may have helped us to grasp the methodology more easily."

> "Some information is too complex to understand or to further work with it; additionally, the question what action should we then take to improve the portfolio is not given."

Another issue highlighted in general terms was the "challenge is to convince colleagues that aligning portfolio with two degree is strategic objective from return perspective." This issue was explored prior.

The road-test was recognized by industry peers in the Responsible Investor Innovation Award – Service Provider.

On average, investors found data at portfolio and company level the most relevant. This result aligns with the impressions from the qualitative feedback. Inversely, only a minority of respondents considered asset data line by line very or highly relevant.

Based on the qualitative feedback, most investors found this graphical representation the most intuitive to understand. The quantitative survey suggests this was not the primary analysis of interest with about one-third of investors choosing the aggregated charts, the forward-looking 'line charts', or the company level 'wheel of fortune' charts as the most interesting respectively (see below).

While many investors asked for more high-level, 'summary' take-away charts, qualitative feedback suggested the current visuals were not intuitive. One key challenge expressed with regard to the analytical bricks is more clearly demonstrating their interaction and the 'take away' message.

The following summarizes the key positive elements or strengths identified with regard to the 2°C portfolio assessment framework – based on a combination of the survey and engagement with industry actors:

- Investors highlighted as a critical innovation the forward-looking nature of the assessment, in particular compared to the current class of carbon footprint data. Forward-looking data is the pre-requisite for comparing portfolios to economic trajectories and linking portfolios to future risks;

- The use of high-quality asset level data is another critical feature of the model, reducing the misleading elements of climate-related data, circumventing to a large degree the gaps in corporate reporting, and allowing for regional-specific assessments;

- Sector-specific analysis allowed for a more granular deep-dive than high-level one size fits all indicators. While the limitation to some sectors was considered a shortcoming by some investors, the model covers around 80% of the GHG emissions of a typical portfolio. It thus addresses the key sectors from a climate perspective;

- The development of a 2°C, science-based benchmark appeared as another key innovation, allowing investors to benchmark themselves not just against the market, but also against climate goals and the Paris Agreement commitments.

- Usability for engagement and stock-picking appeared as a key advantage for investors looking to find meaningful corporate assessments across all companies exposed to climate-related infrastructure for fossil fuels, power, and automobile transport. While this was described as positive feedback, investors also commented that they felt a need for more guidance on how to use the model

The following summarizes the key flaws identified as part of the feedback of the model:

- One of the most frequently cited shortcomings of the model in the anonymous written feedback was its limited sector coverage, given its focus on ~20% of the portfolio. The model misses key business segments (e.g. buses, bicycles, car-sharing, upstream supply chain, etc.).

- SRI and thematic investors argued that the model could not fully capture their thematic tilts.

- The model results are complex and cannot be distilled to a single number.

While the qualitative feedback collected in interviews with institutional investors in the context of disseminating the model and testing it on portfolios, it aligns with the feedback collected more systematically through the feedback survey.

One key element that was not raised in the survey, but that represented a focal point in the discussion was the lack of academic infrastructure around this topic, an issue this thesis of course hope to respond to.

Another issue was the ‘so what?’. Many investors highlighted their reservations about the extent to which portfolio strategies in capital markets can actually have impact in the real economy. It is this specific question that is at the heart of the final section of this thesis.

Part 3
…and that has made all the difference…
The journey forward

8. Towards an impact framework

8.1 Introduction

This chapter seeks to create a framework to understand the extent to which actions around seeking to align portfolios with climate goals can contribute to achieving the climate outcomes defined as international policy goals in the Paris Agreement, specifically limiting global warming to well below 2°C (UNFCCC, 2015).

Potential actions can be categorized as actions related to changes in capital allocation in their portfolios or changes engineered by the investees in their portfolio through engagement. Finally, financial institutions of course influence the broader market environment, for example through signalling to stakeholders (e.g. policymakers) and / or direct lobbying. For the objective of this chapter, capital allocation operates as an umbrella term that covers investment in the production capacity of products and services, changes in operations, and R&D. Capital allocation acts either directly through changes in the financial portfolio of the financial institution or indirectly through changes in the economic portfolio of the counterparties of financial instruments in the portfolio.

The scope of actions that financial institutions can undertake – depending on their mandate, governance, and focus – can cover the following aspects:

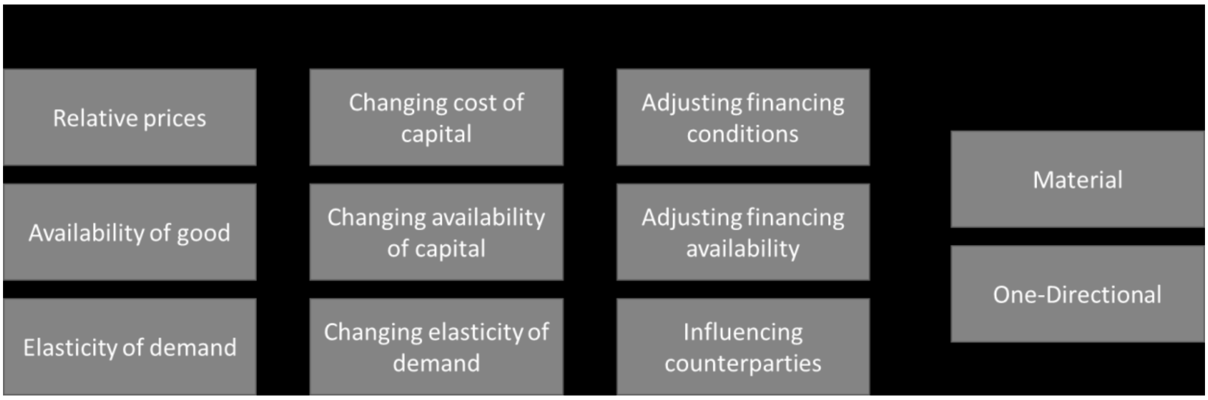
- Use their investment processes - portfolio changes from company to asset level - to affect market pricing such as the cost of capital, as well as the overall availability of capital;
- Influence the investment behaviour of their asset holdings such as listed equities through *engagement* to change the governance, strategy, risk management and capex profile;
- Engage with policymakers on demand and cost incentives to favour low carbon outcomes

8.2 A climate impact framework

The following provides a climate impact framework for institutional investors. The framework is developed by working backwards from impact in the real economy to actions of institutional investors.

The impact starts in the real economy in terms of actual GHG emissions avoided. This implies that any reference point at the other end of the chain as it relates to asset and capital allocation decisions ultimately has to be reflected in that impact.

Figure 33 Linking economic effects to impact



In basic terms, a positive impact in terms of limiting global warming to 2°C is achieved when the consumption of a high-carbon product or service is replaced with the consumption of a low-carbon product or service. The extent to which this impact suffices to achieve the 2°C goal is then a function of the scale (in terms of the number of products being thus replaced and the delta in the relative carbon intensities) and the speed of this pattern.

The extent to which this change materializes is a function of three drivers:

- Relative prices of the two products: Low-carbon products will be consumed when they represent a cheaper alternative than high-carbon products. The challenge around relative prices is that frequently a comparison of relative prices requires some discounting of the lifecycle costs of products (e.g. lower long-term costs of electric vehicle ownership offset against potentially higher upfront costs), which may then be informed by subjective discount rates.

- Availability of the good: Low-carbon products can only substitute high-carbon products if they actually exist / are available for purchase. This can be a challenge in the case of zero-carbon alternatives for industry and non-road transport (e.g. aviation). Similarly, if there are regulatory constraints related to high-carbon products, they are not 'available' anymore as competition.

- The elasticity of demand: Since low-carbon products are frequently not perfect substitutes (that is not to say they are inferior, but may in any event not be exactly the same product or service), the elasticity of demand matters as well. This elasticity of demand may be a function of the relative quality of the product itself (e.g. electric vehicles may be considered inferior to internal combustion engine vehicles given range) or a function of social perceptions (e.g. electric vehicles may be preferred given the positive social status and utility related to 'doing the right thing').

Financial markets generally – and institutional investors in particular – positively influence one or more of these drivers through the following aspects:

- Financial markets influence the financing costs. Changes in the cost of capital can improve relative competitiveness of low-carbon products where financing costs make up a material part of the cost of a product. Changes in the cost of capital for companies in general related to climate can also act as an incentive mechanism to adjust the availability of goods and services (i.e. change investment decisions) independent of the relative competitiveness of an individual product or service. In that case, the cost of capital dynamic can be interpreted through the lens of the cost of a high-carbon good in the context of being delivered by one or another company. This impact is achieved as a result of changes in the supply of capital. Costs in the real economy may also be impacted in the role that financial institutions play in either directly or through their investees influencing the policy process.

- The availability of a good is a function of the investment in production, which requires capital. In addition to the question of cost, financial markets influence the availability of capital, which may in turn impact investment levels, either by withdrawing capital for high-carbon products (thus potentially reducing the availability of the good) or providing capital to low-carbon products.

- Beyond price mechanisms and availability of capital, financial markets and institutions generally play a limited role in adjusting consumer preferences. They may, however, be one source of a broader societal trend that changes the elasticity of demand.

Financial institutions have three types of actions in their toolbox to generate the impact described above:

- Adjust the terms under which capital is provided: Financial institutions can change the conditions under which they provide capital. This strategy is not a blanket adjustment in the actual provision of capital, but rather involves, e.g. adjusting the risk premia or interest rate charge related to high-carbon and / or low-carbon assets. This strategy is underpinned almost exclusively by a financial risk-return perspective. Risk-return perceptions may also be influenced by other factors related to subjective perceptions of the potential of future projects. Thus, financial analysts tasked with demonstrating the viability of a low-carbon investment may be inclined to have the mandate underpinning the analysis inform their model calibration and design. In terms of impact, generally speaking, this action will only actually change the demand for capital if it sufficient to impact the underlying investment decisions – thus being material – and not be offset by other market actors that are willing to undercut the risk premia demanded by an individual institution.

- Change the conditions under which they provide capital: In addition to adjusting prices, financial institutions may also adjust the overall supply of capital to high-carbon and low-carbon projects.

- Seek to influence counterparties and other market stakeholders: Financial institutions as prominent market actors can have an influence on their investees – realized through engagement actions – and thus lead them to change strategies without directly adjust the terms under which capital is provided or the availability of capital. This engagement action is only likely to be effective however if there is a credible threat that non-compliance will affect one of the first two strategies. In limited cases, engagement may also be effective if financial institutions make a relevant business case previously not or under-appreciated by the investee or if there is a behavioural effect. For example, some investors representing religious denominations may have an outsized effect on companies as a result of them being perceived to represent an important market stakeholder independent of financial considerations. Financial institutions may also influence their investee influence, for example through engagement on issues like corporate lobbying, which are not always directly linked to a company's bottom line. This type of engagement is available to financial institutions as well directly.

These actions may be influenced either by financial or non-financial considerations or a combination of the two, which are sometimes difficult to disentangle and which also appear for companies:

- Financial considerations imply that financial institutions' actions are informed by a risk-return optimization perspective.

- Non-financial considerations imply that financial institutions' actions are informed by parameters that are outside of a simple risk-return optimization framework, notably related to social and environmental objectives. While some of these objectives may relate to broader externalities with long-term negative impacts on the economy and potentially by extension financial markets, they are not internalized and thus not intrinsic to financial analysis.

Specifically, the investor actions can be applied as follows:

1. Call for disclosure & disclose. The objective of disclosure it to get data and information that can facilitate debate, analysis and action. Disclosure by companies can lead to internal changes as data informs internal action, and / or enable external stakeholders, whether NGOs, policymakers, or financial institutions, to influence companies' decision-making. Disclosure can allow NGOs to rank companies, and / or policymakers to implement incentive schemes. Disclosure by financial institutions can have replicate the company-level effect at financial institution level (i.e. internal changes as data informs action) and / or have a positive trickle-down effects on companies.

2. Internalize 2°C climate goal price signals ("stranded assets"). The objective of this theory of change is to internalize the price signals of climate goals into investment and financing decisions of companies and financial institutions. This theory of change suggests that investors play a role in internalizing and thus transmitting price signals in financial markets that in turn ensure that low-carbon solutions and high-carbon solutions are priced correctly.

3. Increase allocation to green assets and reduce allocation to brown assets in response to climate policy objectives (non-risk driven). Here, financial institutions adjust capital allocation as a result of climate objectives. This may involve strategies that don't involve any trade-offs in risk-return (e.g. allocating to green investments of a company that are ring-fenced and guaranteed) or may involve changes in the risk-return profile (e.g. allocating to more volatile, small-cap green companies). The distinction here is clearly related to the objective underlying the action and the way it is implemented.

4. Communicate on actions. Finally, actions may simply be communication in the vein of influencing stakeholders.

The following table summarizes the key types of theories of change and how they interact with the different avenues for impact:

Table 8 Climate actions and potential impact

	COST OF CAPITAL	PROVISION OF CAPITAL	INFLUENCING COUNTERPARTIES (DIRECT)	INFLUENCING COUNTERPARTIES (INDIRECT)
1. CORPORATE DISCLOSURE	NA	NA	Investors pressure company to disclose information to drive internal action that influences the internal provision of capital and / or perceptions on the cost of capital.	Investors support policymakers and NGOs by creating increased transparency that can inform policy incentives and / or NGO campaigns
2. INTERNALIZE CLIMATE RISK	Adjustment of financial analysis to internalize climate risk issues	NA, although may affect demand for capital as financing costs change the viability of different investment vehicles	Investors ask companies to internalize 2°C price, volume, and cost signals in order to reduce capital expenditure in high-carbon and increase capital expenditure in low-carbon.	Investors support policymakers in pushing for more ambitious, but smooth climate policies.
3. CLIMATE GOALS	NA, although may affect the cost of capital if supply-demand equation changes	Adjustment of the availability of capital	Investors pressure companies to set and implement science-based targets	Investors signal to policymakers the support for ambitious climate policy action.
4.COMMUNICATE ON ACTIONS	May generate second-order effects			

As can be seen from the results, not all types of actions link to all of the different impact avenues. Intuitively, communication on actions (4) only relates to second-order effects and corporate disclosure (1) only relates to the capital allocation decisions of companies themselves, although they may inform (2) and (3) as the data that disclosure generates may allow for the implementation of these strategies.

Interestingly, the analysis suggests that a 'climate risk' angle actually wouldn't be expected to adjust the supply of capital to companies, but just the cost. This result is not necessarily expected since many investors argue that they are divesting for example from companies motivated by such an angle. The challenge with that premise is that once financial prices adjust / correct for the risk, then one would expect financial institutions to provide capital again as the asset becomes more attractive from a return perspective.

Of course, changes in price may change the demand for capital. Also, hypothetically, there may be a shortage of investors willing to invest at certain risk levels, although this seems a limited issue in the current market. This would imply that the effective value that financial institutions put on the asset is zero, which may be the case, but appears as an extreme example. Of course, if an individual financial institution adjusts the risk assessment and the market does not, the cost of capital is unlikely to move to begin with.

In order for the above actions to actually impact GHG emissions in the real economy, they have to meet the following two conditions:

- Material. Changes in the cost of capital have to be significant enough to actually adjust the relative prices between high-carbon or low-carbon products both at investment decisions and the final moment of consumption or adjust general corporate financing conditions sufficiently to trigger an adjustment of overall corporate investment strategies in order to benefit from generic preferences in financing costs for companies delivering low-carbon alternatives. Similarly, changes in the provision of capital or consumer preferences have to be material enough to actually register as economic effects (e.g. providing $1 more capital to a project that is missing $100 won't have an impact);

- One-directional. Impacts will only materialize if there is there is at best no and at worst only a partial off-setting effect, and where off-setting effects don't impact the materiality criterion. Sometimes this off-setting effect may not even come from financial markets, for example in a case where financial markets withdraw capital, but a government agency offsets this.

The challenge is measuring the applicability of these conditions, in particular as it relates to measuring materiality. Generally, off-setting effects are easier to identify as they can more easily be measured in terms of 'counter-actions' taken by market actors, even if there is uncertainty as to whether they are partial or full. The challenge with regard to measuring the materiality of the effect is more pronounced and requires more in-depth analysis. Indeed, at some level, it may be nearly impossible to measure the true materiality of any effect. Indeed, given the three axes on which financial institutions may have an impact, it is appropriate to bracket out the materiality in the same vein.

Thus, materiality can be considered from a narrow cost of capital perspective (e.g. whether the wind farm now delivering lower costs of electricity than the coal plant), a broad cost of capital perspective (e.g. is the company facing preferential financing rates as a result of having an investment profile consistent with the 2°C transition, even if the cost of capital is calculated across all of the companies business lines), an availability of capital perspective (e.g. is there more supply of low-carbon products and services / lower supply of high-carbon products and services), and an elasticity of demand perspective (e.g. has the action somehow triggered societal change in terms of elasticity of demand of consumers).

One key challenge in this regard is distinguishing first-round and second-round effects. All of these can be identified as first-round effects or second-round effects when they achieve this impact not to the direct target audience, but to other stakeholders. For example, the Divest movement may not impact companies decision-making directly but may create social stigma related to fossil fuels that influences consumers. Another example may be policies, where investor action signals to policymakers that they have support from financial markets for a more ambitious policy agenda. This final point is the most difficult to measure since it relates to second-order or third-order effects. Of course, changes in the availability of capital may not by themselves materially impact GHG emissions. This is also difficult where the potential materiality effect may be a first order effect (e.g. a coal-fired power plant is not built because nobody is willing to finance it), but the offsetting effect is a second-order effect (e.g. another actor builds a coal-fired power plant through their own capital that takes that original coal-fired power plant's space). Issues of measurement will be revisited in Section 4.

The interface between cost and availability of capital and climate impact

The cost of capital issue can appear at a number of levels, all of which have their own financial analysis framework:

- An institutional investor could directly make infrastructure project level investments (most likely in green investments) ;
- Companies make direct investments too so institutional investors as shareholders/custodians of capital could seek to influence those decisions;
- Or institutional investors can buy or sell the company itself affecting the economics of their capital allocation that way;
- Finally at an even higher level asset allocation can affect outcomes as well

Cost of capital plays an important role in the costs of projects. Financing costs matter for project finance. Cost of debt for example for onshore wind fluctuates between ~4-12% in Europe, and the cost of equity can reach 13% (Bank for International Settlements (b), 2017). By extension, financing costs can make up over 10% of the project costs in Europe. In developing and emerging economies, these costs are even higher, with analysis for India by the Climate Policy Initiative suggesting financing costs constituting upwards of 30% of total project costs (Climate Policy Initiative, 2014).

Differences in the cost of capital between different assets can potentially adjust the relative costs of capital, although they will likely have to be significant to be material. Moreover, as will be discussed later, they need to be tangible to the extent that an individual financial institutions' perceptions on costs of capital are not offset by other institutions.

Cost of capital also is critical from the perspective of companies. The cost of capital for a company is much more complex to disentangle since it doesn't neatly fit into one or the other projects categories. Companies may be investing in both high-carbon and low-carbon technologies at the same time. Moreover, they also relate to a companies views with regard to past investments. The cost of equity and debt is not just a function of the capital allocation related to future investments. The cost of capital of a utility investing 100% in renewable power will be a function of financial institutions' perception of risk related to the utilities' existing coal asset base. This makes the cost of capital effect more complex to parse in terms of its impact on investment and production decisions and indeed the interpretation of the relative costs of goods.

For example, renewable power provided by a large company with lower costs of capital will be cheaper than that provided by a company with higher costs of capital, independent of the broader business of the company. The key takeaway is that cost of capital impacts in the real economy is intrinsically linked to the types of companies delivering the products and services on which the transition to a low-carbon economy relies.

Finally, cost of capital can also drive decision-making among financial institutions. This is true in particular for banks, who tap into capital markets for the purpose of refinancing loans through e.g. asset-backed securities. Economic competitiveness of low-carbon products can benefit from lower costs of capital – which can be expected to materialize when financial institutions internalize the assumption that low-carbon scenarios will materialize.

The thesis distinguishes between (1) rational economic underpinnings to the variables in the DCF that sit within mainstream finance theory, leading to specific allocations in the economy and (2) behavioural economics which uncovers how to influence actors around those inputs and decisions. Behavioural approaches ultimately have to influence capital allocation through impacts on rationale theories e.g. working to persuade an analyst to use a demand forecast closer to a 2°C scenario which then affects an investment decision.

The impact transmission mechanism of the cost of capital angle can be seen from two perspectives:

- Option A is that markets already perfectly integrate assumptions around ambitious decarbonization. In this case, financial markets are already properly 'levelling the playing field' for low-carbon investments. However, additional adjustments driven by non-financial considerations can be imagined. Thus, there is some evidence for a 'green premium' for green bonds that operates independently of risk considerations, since the risks for the green bond versus the 'non-green' bond of the issuer should be identical;

- Option B is that markets are not perfectly integrating assumptions around ambitious decarbonization. This may be for a number of different reasons, as highlighted above. In this case, internalizing these assumptions can help improve the cost of capital of low-carbon investments and make high-carbon investments potentially prohibitively expensive to finance.

Assumptions around ambitious decarbonization outcomes can impact the four core variables of financial analysis:

- Costs & Prices. Economic costs and prices will change in the context of the transition to a low-carbon economy. This relates in particular to potential policy costs (and incentives), commodity costs (e.g. oil, gas, and coal), and technology costs related to learning curves.

- Volume. The starting point for most modellers is to get a view of demand which feeds into the forecast for volume in the model. This brings up the issue of scenario analysis and deriving a most probable outcome for an actual set of estimates in the valuation model. It reflects a type of risk which is best thought of as economic uncertainty. Barriers here are significant in terms of getting useful and granular estimates of demand across sectors.

- Discount rate / risk premium. While a broad and deep topic in the context of finance, the thesis distinguishes at least 2 uses of the word: namely (i) to describe uncertainty around an economic variable such as demand or price; and (ii) technically in the sense of Modern Portfolio Theory measured by the standard deviation of returns or volatility. There are several ways to derive the risk premium. It could be from the historic returns of debt and equity in excess of the risk-free rate. It could be derived from the CAPM equation such that it is the beta of the asset relative to a market.

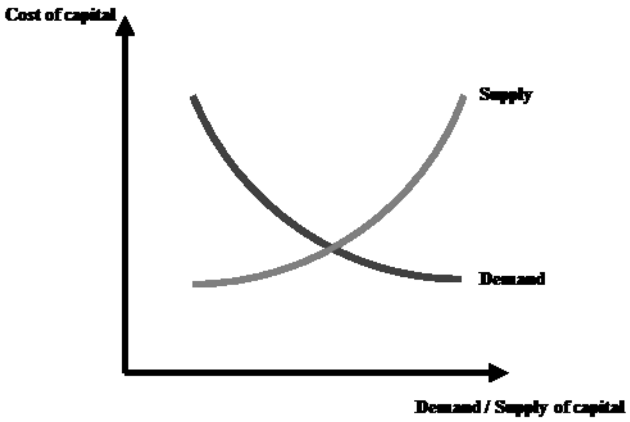
- Model choice. One key prerequisite of a proper link between financial analysis and climate risk is mobilizing long-term models. In terms of valuation models, only a DCF using long-term estimates is fit for purpose when it comes to climate time frames. Other models such as P/E or payback are far more short-term focussed.

8.3 Cost of capital approaches

The following highlights how cost of capital approaches can impact both the relative costs and availability of a good in the real economy:

The framework starts with a basic supply-demand framework where demand for capital goes down as financing costs (cost of capital) go up and supply goes up as return of capital increases (see Fig. below). Climate actions by financial institutions can impact this supply-demand framework in the following ways:

Figure 34 A basic supply-demand framework demonstrating the relationship between the cost of capital and demand / supply of capital



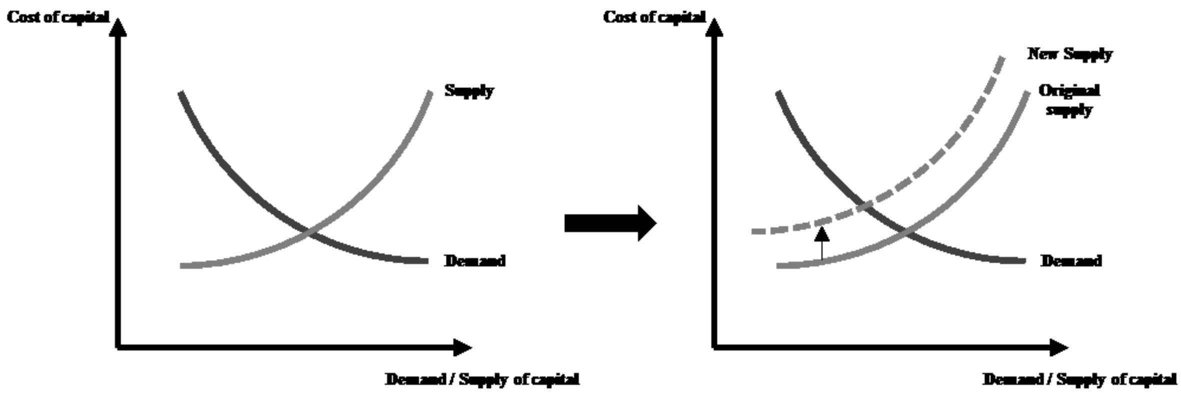
The impact frameworks described here in all cases link back directly to the original ways to impact climate action, namely changes in the availability of high-carbon and low-carbon alternatives. The changes in the supply or demand curves thus either reduce the overall availability of high-carbon products or make them more expensive in financial markets.

1) *The supply curve adjusts – Financial institutions internalize 2°C aligned parameters in their analysis*

Internalizing assumptions about a decarbonized future is likely to increase the cost of capital for high-carbon products as a result of the changes in the model inputs described above. The figure below highlights the implication of this effect, leading to a new equilibrium at lower demand for capital and higher costs. The increased cost of capital reduces demand for capital and thus the availability of high-carbon goods. High-carbon goods that are still delivered to the market are more expensive and may make low-carbon alternatives more attractive.

Of course, the inverse relationship then holds for the supply of capital for low-carbon alternatives where the supply curve shifts downward. In this case, the availability of low-carbon alternatives is increased, and the financing costs of these alternatives are reduced.

Figure 35 Changes in market assumptions moves the supply curve upward, leading to a new equilibrium



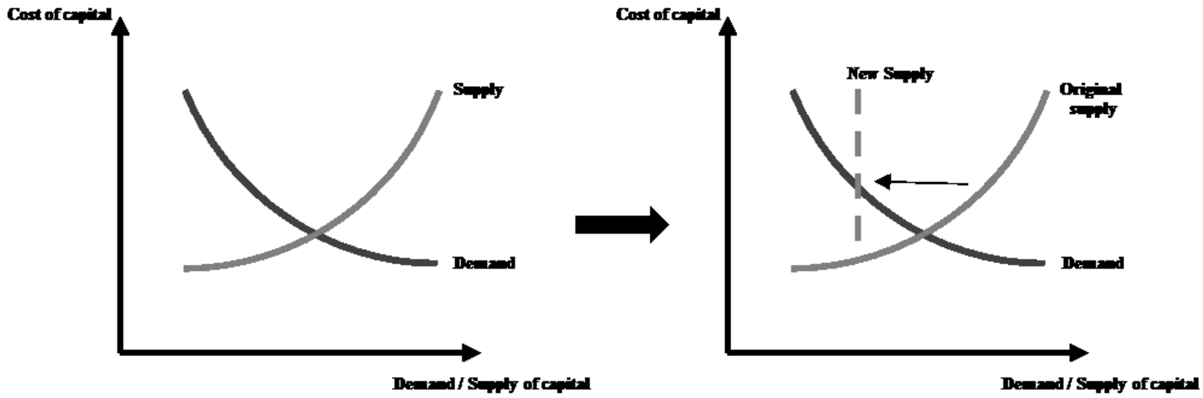
2) *The supply curve becomes non-linear – Financial institutions will no longer finance above a certain demand for capital*

Another potential impact of financial markets is making the supply curve non-linear. There may be two reasons for this. The first reason is that increased uncertainty as a function of the transition to a low-carbon economy leads financial institutions not to finance / invest above a certain level of output (which results from the associated demand for capital). This uncertainty may lead to the risk premium increasing to a degree where all projects above a certain level of supply have a negative net present value. A related reason for this may arise when introducing the assumption that the framework operates in a capital-constrained world, where certain levels of risks cannot be matched with investors interested in supplying capital. For example, in the case of the subprime crisis, capital dried up even at higher levels of return given risk-aversion. Capital-constrained outcomes may also appear in certain asset classes like venture capital or even infrastructure, where higher costs of capital – and by extension higher potential returns – don't lead to higher capital availability.

Another reason for non-linear supply may be that financial institutions manage to solve the collective action problem and recognize that only a certain amount of demand for capital is consistent with a 2°C world. In this outcome, capital is not provided above that level of demand. This, while technically possible, would require financial institutions to a) agree on such a level across all market actors thus ensuring one-directional impacts, and b) for their to be a framework to discriminate demand for capital. One framework for the fossil fuel sector is the use of cost curves, applied by the Carbon Tracker Initiative (Carbon Tracker Initiative, 2015) and equity research analysts.

There is another factor that may adjust the supply curve, namely related to effects outside of the 'model'. These relate for example to potential reputational or legal risks to the financial institution. Thus, supply may be non-linear because banks fear reputational repercussions around financing certain projects or companies. Similarly, they may fear legal risks. Naturally, the effects described here can also be coupled with the effects related to a more general shift of the supply curve described above.

Figure 36 The supply curve becomes non-linear above a certain point

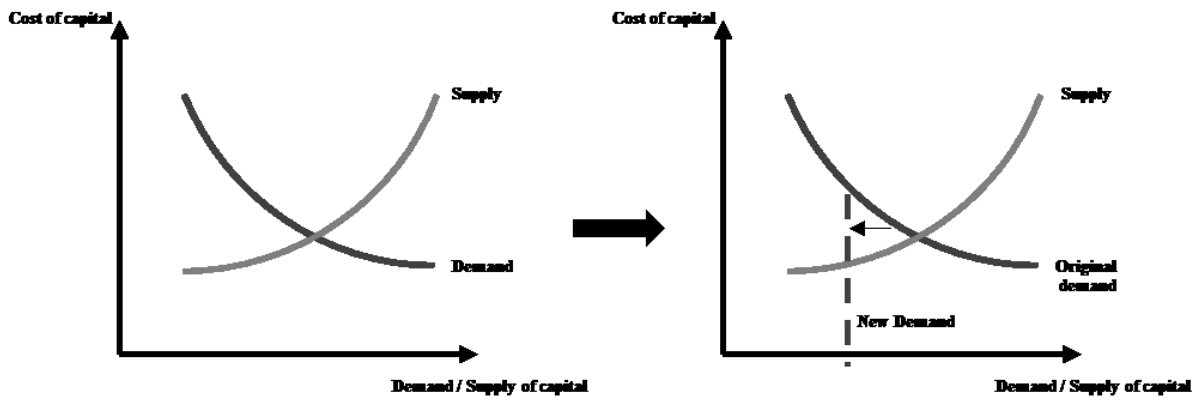


3) Changes in the demand for capital

Financial institutions can influence the supply of capital. They can also influence demand through a number of different channels. First, in providing access to capital to companies, they can help push the hurdle rates upwards, above which an investment isn't sanctioned. In this process, demand at some point becomes non-linear and disappears since higher costs of capital eliminate demand for capital above a certain level. In the context of limited access to capital (internal and external), companies won't supply capital to projects that don't exceed the hurdle rate, so they don't 'supply the capital' internally (this is different to changes in the demand for capital.

Financial institutions can also engage with companies on limiting demand for capital, for example through changing companies' perceptions on the viability of investments. Thus financial institutions could help companies internalize the notion that output above a certain level is inconsistent with the 2°C goal such that this output is no longer desired. The challenge here is similar to the one described above for the supply of capital, and potentially even more so since companies will both have internal expertise on this in many cases potentially divergent from financial institutions' views and secondly, most companies assume they will deliver 'the last drop of oil'.

Figure 37 The demand curve becomes non-linear and 'stops' at a certain level.



Seeking impact through cost of capital approaches can have unintended consequences, notably that the equation reverses.

The framework above relies primarily on a 'climate risk' angle. This implies that financial institutions internalize these risks. There may be cases where this approach has unintended consequences:

- Green bubble: Financial markets may over-adjust, leading to an over-allocation to green assets. Such an outcome may be desirable from a climate perspective, but less desirable from a financial efficiency perspective (at least in the short-term);
- Distributional effects. Changes in cost of capital, etc. will have potentially knock-on distributional effects. This of course is a broader climate challenge, but nevertheless worthwhile highlighting.
- Markets don't internalize 2°C assumptions collectively. If markets don't internalize the assumptions as a collective, none of these effects described above will be one-directional as other market actors may consider certain companies to be under-valued.

- Market flooding. Another unintended consequence may be that companies internalize the notion that long-term demand will be constrained and will seek to be ‘first to market’ even at lower rates of return, thus potentially flooding the market and depressing the prices of high-carbon assets.

- Assets move into private markets. One potential driver of engagement will be that assets move into private markets (e.g. non-listed ownership) given that listed companies can’t monetize them. This may reduce the leverage of financial markets in impacting the actions in these markets. Indeed, the presence of private markets more generally creates a challenge for creating one-directional effects, since not all decisions are under the ‘purview’ of financial markets.

9. The implications for financial policy frameworks

This section will explore the role of policymakers in both the use and application of indicators that measure the 2°C alignment of financial portfolios. Of particular interest in this discussion will be questions related to creating transparency in financial markets, although the discussion will also extend to moving beyond transparency to incentive regimes.

The conversation around potential policy interventions in financial markets designed to support the transition to a low-carbon economy was first put on the agenda at the beginning of the decade by the 2° Investing Initiative (2° Investing Initiative, 2012) and other organizations (Carbon Tracker Initiative, 2013). The topic over time gained steam with the launch of the UNEP Inquiry on the Design of Sustainable Financial Markets (UNEP Inquiry, 2014) and the beginning of a comprehensive policy mapping (2° Investing Initiative (c), 2013). Regulators and policymakers like the European Commission (Financing the Future Consortium, 2014) and the Bank of England (Bank of England, 2015) started commissioning first research.

Since then, the policy agenda has been picking up speed. The EU commissioned a High Level Expert Group on Sustainable Finance in 2016, which published their results in February 2018 (EU High Level Expert Group on Sustainable Finance, 2018). The EU has since then published its own Sustainable Finance Action Plan laying out a series of policy interventions across issues like a ‘Green Taxonomy’, fiduciary duty, climate disclosure, green bonds, and the integration of non-financial objectives by retail investors.

This builds on a series of policy interventions, including the previously highlighted mandatory climate disclosure legislation in France (2° Investing Initiative (b), 2015), the climate disclosure pilot in Switzerland (2° Investing Initiative (b), 2017), as well as policy interventions across developing market geographies analyzed by the 2° Investing Initiative (2° Investing Initiative (c), 2013) (2° Investing Initiative (a), 2016).

The suit of policy intervention options on the topic of integrating non-financial objectives into financial markets or more generally rekindling the link between financial markets and economic criteria is broad and cuts across a range of policy fields, related to the responsibilities of central banks, financial supervisory authorities, as well as economic and financial policymakers.

The following table summarizes the range of policy options identified in the literature.

Table 9 Overview of potential financial policy interventions (2° Investing Initiative (c), 2013)

TYPE	INSTRUMENT	EXAMPLE
Monetary Policy Instruments	Quantitative Easing	*"Integrate long-term and climate investment needs in QE considerations"*
	A carbon-linked monetary instrument	*"Create carbon assets that can serve as legal reserves with central banks"*
	Collateral frameworks	*"Improve the liquidity of 'green' assets through preferential treatment in collateral frameworks"*
Financial Regulation	Stress-testing	*"Integrate carbon risks into stress-testing frameworks"*
	Capital reserve requirements	*"Expand the scope of portfolio matching by insurers in the context of capital reserve directives"*
	Lending guidelines	*"Establish guidelines for integrating environmental considerations and risks into investment processes"*
	Lending mandates	*"Establish lending restrictions for 'high-damage' sectors"*
	Bond markets	*"Expand the rules for covered bond markets to increase the issuance of 'green' covered bonds"*
	Mortgage markets	*"Provide incentives for climate-friendly home ownership in the framework of mortgage origination"*
	Carbon markets	*"Design carbon markets under a regulatory auspice that guarantees transparency"*
	Benchmark investing	*"Mandate 'diversification assessments' of mainstream indices and strengthen associated reporting"*
	Stock exchange regulation	*"Implement rules increasing the rigour around entry criteria and index construction."*
	Banking rules	*"Expand the definition of fiduciary duty to include sustainability criteria"*
	Credit rating agency regulation	*"Strengthen the rules regarding carbon risk reporting for credit rating agencies.*
Public Incentives	Tax incentives	*"Provide tax incentives for savings' interest and pension fund benefits that invest in low-carbon assets"*
	Public initiatives	*"Utilise public-financing schemes (e.g. PACE bonds) to incentivize energy-efficiency in real estate"*
	Public banks	*"Leverage public banks to increase private investment in 'green' assets"*
Accounting & Disclosure	Developing new metrics	*"Invest in developing and adopting more sophisticated carbon metrics reflecting both climate-friendliness and carbon risk concerns"*
	Disclosure for non-financial companies	*"Improve reporting standards and requirements for non-financial companies"*
	Rules governing KIDs	*"Integrate climate-friendliness and carbon risk indicators in KIDs"*
	Disclosure for financial companies	*"Strengthen carbon disclosure requirements for banks and other financial institutions"*
	Disclosure to regulators	*"Expand the reporting requirements to financial regulators"*
	Public banks reporting	*"Road-test new reporting metrics by public banks"*
	Stock exchange reporting	*"Extend the carbon reporting requirements of stock exchanges"*

A range of these are considered by the High-Level Expert Group and the EU Action Plan. While not considered in the action plan, work on central banks and financial supervisory authorities, including questions around the use of the central bank balance sheet in the context of quantitative easing (Matikainen, Campiglio and Zenghelis, 2017) and ideas around the so-called Green Supporting Factor (Thomä and Hilke, 2018).

In terms of the model infrastructure developed in this thesis, of particular interest are undoubtedly issues related to disclosure, accounting, and climate transparency more generally.

Climate transparency in financial markets can have three key objectives (2° Investing Initiative (a), 2016):

1. The first objective may relate to monitoring risk. The European Systemic Risk Board (ESRB 2016) and Bank of England (Bank of England, 2015) have highlighted the extent to which physical risks and / or a delayed transition may have implications for financial stability at either macro- or microprudential level. Such dynamics may also be relevant from the perspective of the proper pricing of risks in financial markets (see Chapter 2) and the efficient allocation of capital.

2. The second objective can consider a broader suite of 'economic' or social policy objectives, notably relating to monitoring the alignment of financial markets with Art. 2.1c of the Paris Agreement, which calls for "making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" (UNFCCC, 2015). As highlighted by the 2° Investing Initiative (2° Investing Initiative (a), 2016), "this goal is similar to the first goal, as it monitors system trends via entity-level transparency, but the primary user (environmental policymakers) and intent are different due to the different mandates of financial supervisors vs climate policymakers. This monitoring can help inform on the extent to which long-term climate policy signals are integrated by private sector actors and the potential need for policy 'ratcheting'."

- The final objective does not consider financial or environmental policymakers as a direct user, but rather the need for transparency to allow financial institutions and retail investors to integrate non-financial or 'climate risk' objectives into investment decisions. This builds on arguments around market efficiency and the need for information to ensure capital is allocated in a way that is consistent with the financial and non-financial objectives of users.

The table below summarizes the potential levels of disclosure and different types of users.

Table 10 Users of information by level (2° Investing Initiative (a), 2016)

USERS	Investment products	Financial institutions				Financial markets
		Asset managers	Listed asset owners	Non-listed asset owners	Banks	
Financial Supervisory authorities		✓***	✓	✓	✓	
Stock market regulators	✓*		✓		✓	✓
Climate policymakers		✓	✓	✓	✓	✓
Retail investors	✓					
Institutional investors	✓**	✓	✓		✓	

*** Listed investment products **Largely already provided through voluntary mechanisms *** In its capacity as intermediary**

Quantitative financial institution climate transparency can be achieved through two different models: disclosure of holdings vs disclosure of key performance indicators (KPIs). Additionally, for some objectives qualitative disclosure on actions may also be appropriate.

In terms of disclosure of holdings, this reflects a logic of disclosing the underlying portfolio holdings, either directly to a financial supervisory authority or publicly. Public disclosure of portfolio data for example is mandatory for Swedish public pension funds (OECD, 2012) and insurance companies in the United States (Naic.org, 2018). Disclosure of portfolio data in turn to financial supervisors is mandatory in Europe for insurance companies under the Solvency II Directive (*Directive 2014/51/EU*) and as part of the Anacredit initiative for banks (European Central Bank, 2018).

Disclosure of underlying portfolio data allows interested parties with access to this data to conduct their own analysis. In applying one consistent model, this ensures comparability across institutions and allows users to apply the model or performance indicator that is consistent with their use case. WWF for example has in the past capitalized on this information – enriched by portfolio disclosure of other asset owners directly to WWF – to analyze the 2°C alignment of European asset owners, building on the model developed in this thesis (WWF, 2017). Similarly, financial supervisors are starting to use this data to analyze the climate risk exposures, notably by the Dutch Central Bank (Dutch Central Bank, 2017), Bank of England (*publication forthcoming)*, and the California Insurance Commissioner (*forthcoming*). This type of analysis is – for example in the case of California – then potentially complemented by additional survey information (Jones, 2016).

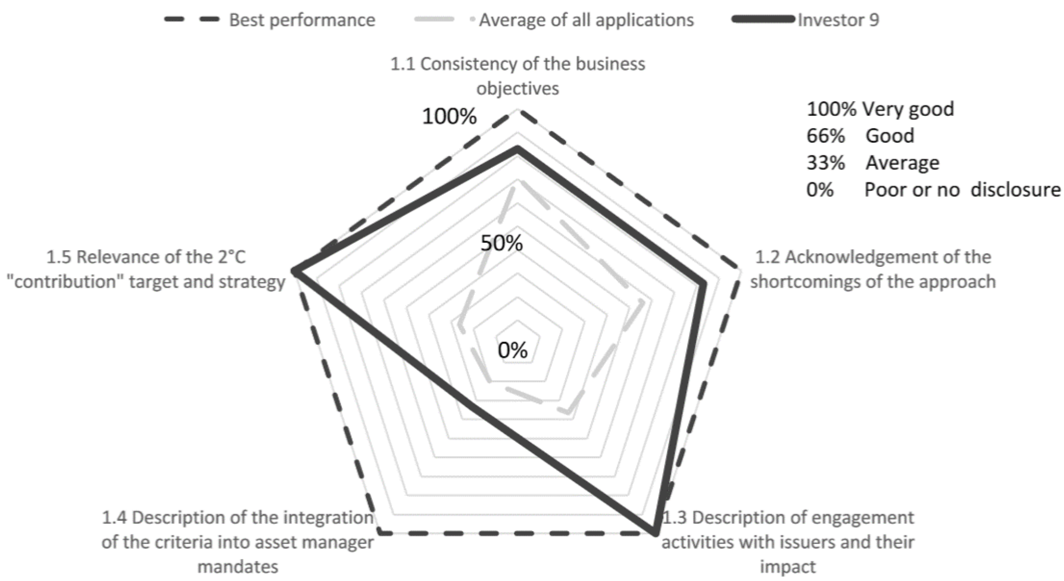
The second type of approach relates to disclosure frameworks related to key performance indicators. This could for example relate to disclosure on climate-related risks, or alignment with climate objectives. This approach is the one taken by the French Energy Transition Law Art. 173 on mandatory climate disclosure (2° Investing Initiative (b), 2015). It is also the spirit of the recommendations of the recommendations of the Financial Stability Board Task Force on Climate-related Financial Disclosure (Financial Stability Board, 2017). This type of information could for example related to disclosing a science-based target (Science-based Targets Initiative, 2014), or the results of 2°C scenario analysis, as conducted by TPT Retirement Scheme (TPT Retirement Scheme, 2017).

The predominant transparency model today is focused on public reporting of KPIs and actions. As part of the climate disclosure awards organized by the French Environment Ministry, Treasury, and the 2° Investing Initiative, three categories were identified, further elaborated in a best-practice guide published in 2017 (2° Investing Initiative (e), 2017):

- Risk-related reporting: reporting on the results of scenario analyses and portfolio risk assessments
- Alignment with climate goals: reporting on the alignment of the portfolio with climate objectives (e.g. 2°C)
- Proxy metrics: simple KPIs acting as a proxy of climate-related risk or alignment (e.g. carbon footprint, green ratios)

The figure below highlights the performance against the various categories in the context of the climate disclosure awards described above of the 30 disclosures that were submitted for review

Figure 38 Rating of climate disclosures by category (2° Investing Initiative (e), 2017)



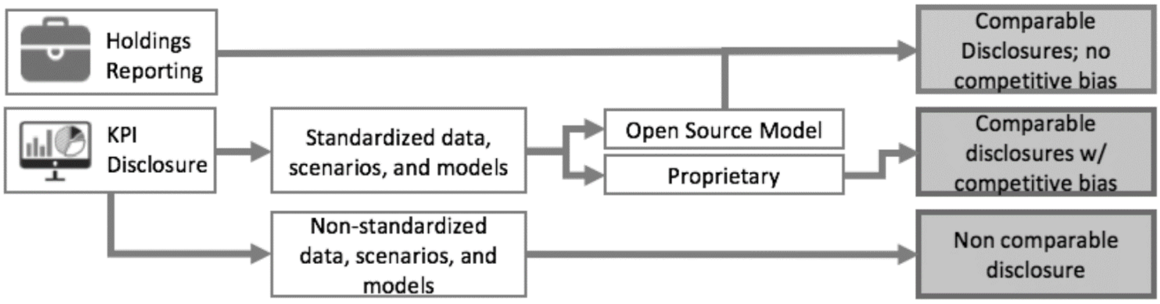
Finally, disclosure could also be of qualitative nature, related to strategies, actions taken, and / or investment beliefs.

In terms of the relative merits of different approaches, these relate to questions of ensuring comparability, minimizing reporting burden, and responding to the particular use case, as well as broader questions of how impact is generated. Each of these aspects will be briefly reviewed.

Comparability of disclosure is obviously critical for it to be usable. Holdings reporting intuitively achieves this, given that in this case the original portfolio data is provided. The reporting burden here is also potentially low, since this type of data is just portfolio information that already exists. Costs may arise if the reporting 'template' is inconsistent with internal data systems of financial institutions. Other issues may relate to confidentiality, especially for banks that guard their information on their lending portfolio closely. In terms of use case, it also gives a wide array of options for different actors to apply models that fit their use case. Critical to highlight however that the costs here then get shifted from the financial institutions shift to the users of information, which may be distributed (assuming users involve the global universe of financial institutions or investors) or centralized (e.g. financial supervisory authorities), in which case costs are lower.

The figure below highlights the conditions under which comparability can be achieved both for holdings and KPI disclosure.

Figure 39 The impact of various disclosure approaches on comparability (2° Investing Initiative (a), 2016)



While KPI reporting does not deliver on these criteria, it does potentially incentivize innovation and gives those that provide disclosure the liberty to present the information in the way that fits their perspective and their specific business model – including of course potentially extending to strategy. One aspect in this regard may be investors who have significant exposures to high-carbon sectors, but deploy a strategy of engaging with these organizations in order to shift their business model. Pure holdings disclosure will fail to flag this.

According to the 2° Investing Initiative (2° Investing Initiative (a), 2016), "ultimate costs will differ based on the type of analysis and the coverage of financial assets. We have previously estimated that a mid-sized asset manager reporting on risks and climate alignment for corporate bonds and listed equity will likely pay around EUR 10,000 – 50,000 in the current market, although that represents a ballpark estimate based on current metrics. For a regulator, internalizing the same assessment for all regulated entities invested in these asset classes can rely on automated open-source software, and likely requires data purchases of around EUR 100,000 per annum. […] Building new models can obviously be very expensive."

Ultimately, the real world impact of transparency in financial markets relates to the objectives and the implementation. The impact of transparency with each of these actors can be conceptualized through three key steps:

1. Is the information tracked by the target audience? Are the users actually using the information or is this 'transparency in a vacuum'.

2. Are decisions affected? Even if information is consumed, does it actually inform investment or financing decisions.

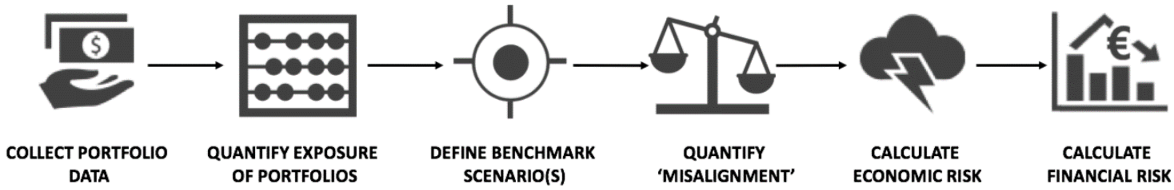
3. Does this impact the real economy? If the information is used and acted upon, do these actions actually imply an impact in the real economy.

In the context of this broader framework on climate disclosure and transparency, the model developed in this thesis presents one type of framework that can be applied either by financial institutions directly in the context of climate disclosure mandates of the kind developed in France, as well as by financial supervisory authorities.

A number of financial supervisory authorities, notably the Bank of England, California Insurance Commissioner, and the Dutch Central Bank have already applied the model on the data reported to them by their regulated entities. Other authorities are currently exploring an application. Their work relies on existing portfolio data collected by these authorities, a quantification of the portfolio exposures, a benchmarking of these exposures to a scenario, and a subsequent quantification of misalignment.

Their analysis may also go further than the models and frameworks developed in this thesis and seek to quantify directly both economic and financial risk (see Figure below).

Figure 40 The steps for supervising transition risks and Art. 2.1c alignment financial supervisory authorities and environmental policymakers (2° Investing Initiative (g), 2017)

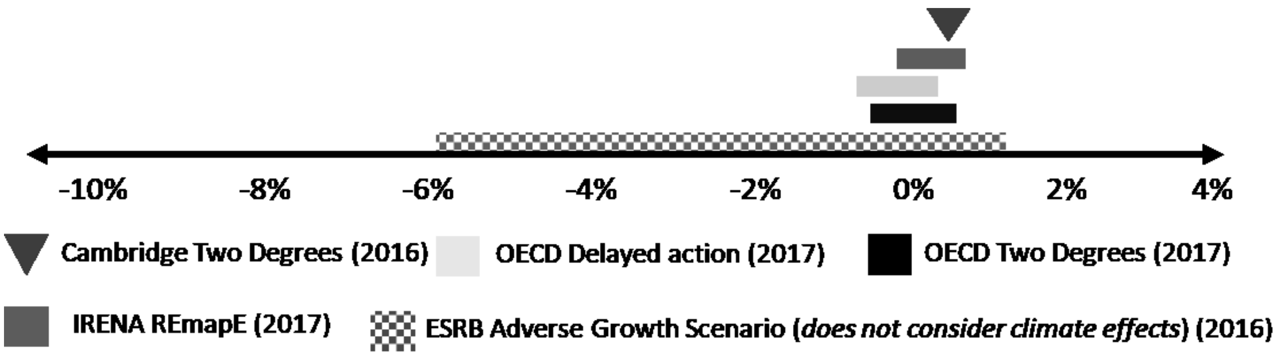


The model thus provides for an infrastructure that can inform disclosure and supervisory regimes. For environmental policymakers, this function focuses primarily on the alignment of financial markets with climate goals. Supervisors in turn see this infrastructure both as a way to measure potential deviation between economic trends and those in capital markets, as well as a potential gauge of what can be labelled 'accumulating transition risk' – in other words a signal that as financial markets deviate from the 2°C scenario in the short-term, this may give rise to risks in the medium to long-term, a type of 'Climate Minsky' moment.

Indeed, the framing suggested here is interesting as it responds to two challenges. The first challenge is that traditional short-term stress-testing frameworks are unlikely to capture the risks of interest in this context. This is a function both of the time horizon of these stress-tests (usually 3 years or less) but also the fact that the risks are at sectoral and sub-sectoral level.

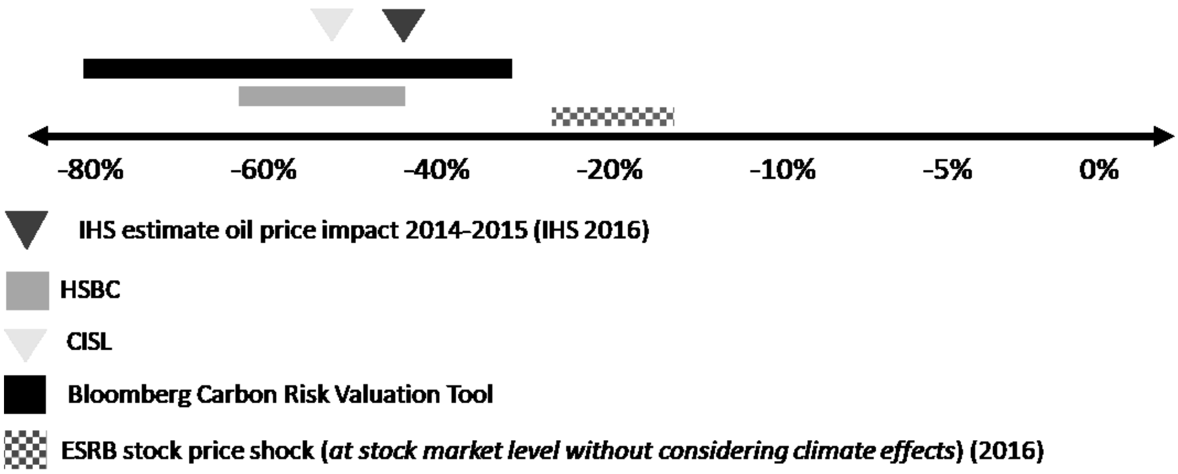
Thus, a traditional stress-tests that captures macroeconomic trends in terms of changes to GDP will only see a muted effect, given the positive netting of the 'green economy' that may offset the negative GDP (potential) GDP shocks from the 'brown economy'. The figure below demonstrates this muted phenomenon based on a review of scenarios quantifying GDP effects associated with the transition to a low-carbon economy and comparing these to the 2016 European Systemic Risk Board Adverse Growth Scenario.

Figure 41 Impact of transition risk on growth (2018-2020) (2° Investing Initiative (d), 2017)



On the other hand, micro effects may be more significant. Indeed, when mapping some of the studies cited earlier in terms of potential risks, the sectoral shocks significantly outweigh the shocks estimated in the ESRB Adverse Growth Scenario in terms of shock price shocks, by a factor of up to 3x or even 4x as much (Figure below).

Figure 42 Estimated equity price impacts for developed markets oil & gas equities compared to the ESRB stock price shock in the adverse growth scenario (2° Investing Initiative (d), 2017)



These effects suggest two things. First, microprudential supervision of these risks may be a relevant endeavour for financial supervisors seeking to track sector-specific exposures. Analysing these exposures through a climate lens – the way the model developed in this thesis allows – provides for a pathway to understanding potential concentration risks that individual financial institutions may face.

Second, given the fact that risks may not materialize in the time horizon over which supervisors regulate their entities, of interest here may be the opportunity to track whether financial institutions are accumulating transition risk – as outlined earlier – to provide an early signal system and potentially reach a point where financial supervisors can contribute to an efficient allocation of capital that internalizes economic and societal goals.

The first paragraph of this thesis argued that financial markets is not where final investment decisions necessarily get made. These are under the purview of the households, governments, and companies. At the same time, as highlighted in the previous chapter, financial markets may have an impact on these decisions.

From the perspective of financial supervisors, the exercise described here may thus simply be a way to monitor whether risks are building up or decreasing relative to a specific type of economic and social outcome. In the first case, further analysis as to the implications of these risks for regulated entities may be warranted.

Equally interesting perhaps in this context may however also be the opportunity for financial supervisors to realize the lighthouse function of financial markets, pointing the way to where the economy is headed and whether that direction is consistent or not with broader economic and social outcomes. The unique role of financial markets in providing the capital for the economy of tomorrow makes this type of exercise fundamentally different to traditional backward-looking frameworks. In this vein, financial supervisors have the opportunity to stand at the end of the cycle reconnecting financial markets to the real economy.

Conclusion

The thesis reflects and brings to paper a conversation about the principles governing the allocation of capital in a capitalist system. The conversation took us from fireside chats with religious authorities (the Talmud, Qur'an), oratory peaks from the stage inspired by literary greats (Shakespeare, Frost), and dialogues with the luminaries of the Renaissance and Enlightenment (Cardano, Smith, Mill), to the academic titans in economics (Marshall, Robbins, Knight, Keynes, Bowles, Simon), and finance (Markowitz, Sharpe, Fama, Tobin, Modigliani).

At its end is a simple idea, the idea that capital should be allocated in a way that is consistent with the highest societal utility, that that utility is multi-dimensional and thus not always reflected in the prices of assets,[25] and that by extension a model is needed to translate non-financial societal objectives into capital allocation and portfolio management frameworks.

This simple idea – in this thesis – is turned into a mathematical model that allows for a quantification of financial portfolios alignment with societal objectives as expressed in specific economic outcomes, in this case the goal of limiting global warming to well below 2°C above pre-industrial levels. The model is developed for global capital markets related to companies – specifically listed equity and corporate bonds – and goes on a journey to link these markets with the real economy and societal goals.[26] The model starts at the vision for a better society – specifically one that limits global warming – and ends at the reality of the trajectory on which society is on. In between, it weaves the owners of economic activity, their financial instruments, and portfolios together and connects that to an economic journey consistent with the vision for a better society. This red thread is the one needed to interface finance and the real economy and link through myriad ownerships, the economy with financial markets and societal goals.

The model is at its heart an articulation of a capital allocation framework that goes beyond Dollars and cents, risk and return, and reconnects finance with the real economy. An objective that has been haunting the academic and practitioner world both pre- (Bank for International Settlements, 2005), but also in particular post the global financial crisis (Krugman, 2009) (Thomä, 2014) (Bank for International Settlements (a), 2017).

[25] A function of the simple truth found in Mark 8:36 that "for what doth it profit a man? If he gain the whole world, but forfeit his own soul" (The new English Bible, 2009)

[26] Of course there are those who argue, like French financier Marcel Labordére to his friend John Maynard Keynes, that "Man will never be able to know what money is any more than he will be able to know what God is." (qtd. in Skidelsky (Skidelsky 2013))

Perhaps it is also more. Perhaps it can represent an alternative way to think about 'optimal diversification' – the most powerful concept in financial markets over the past half-century – insofar as it creates a new power to think about diversification not from a *financial*, but an *economic* perspective.[27]

Channelling my inner 'Frank Knight' (see Footnote 9, p. 70), at its heart, this concept is neither new nor original. The Talmudian 'eggs' were eggs, not financial assets. Even Markowitz (Markowitz, 1952) concludes that (and again, it is worth citing here in full) "The adequacy of diversification is not thought by investors to depend solely on the number of securities held. A portfolio with sixty different railway securities, for example, would not be as well diversified as the same size portfolio some railroad, some public utility, mining, various sort of manufacturing, etc. The reason is that is generally more likely for firms within the same industry to do poorly at the same time than for firms in dissimilar industries."

Markowitz identified this simple idea on p. 89 of his article in the Journal of Finance, but never articulates it mathematically. The quote is immediately followed by a diversion: "Similarly, in trying to make variance small it is not enough to invest in many securities. It is necessary to avoid investing in securities with high covariances among themselves. We should diversify across industries because firms in different industries, especially in industries with different economic characteristics, have lower covariances than firms within an industry."

Economic diversification in Markowitz is reduced to financial covariance. This thesis seeks to resurrect it. In doing so, it provides a rigorous analytical framework that can help measure and benchmark economic diversification. The benchmark here is the 2°C scenario. But it could just as well be the market or any other economic outcome.

The framework can be interpreted to fulfil the original vision of Markowitz. Instead of building on the acolytes of Markowitz and the decade-long tradition of risk factors – a tradition incidentally that has also captured the transition risk conversation (Andersson, Bolton and

[27] The conversation about moving from a financial to an economic perspective is not just (literally speaking) an economic, but also a social question. In his book "Unter Amerikanern: Eine Lebensart wird besichtigt" (Among Americans: A Lifestyle under review") (Thomä 2001), Dieter Thomä highlights the fact that in the United States, "Shareholder value has become the standard beyond just the economy. No politician searching for majorities would say a bad word about the moneyed men. (…) The power of the shareholders is uncontested, the prestige of the financial jugglers excellent and the dependence on them significant." His philosophical work highlights the potential benefit of reorienting finance not just for the sake of finance itself, or even the economy more broadly, but also society as a whole.

Samama, 2016) – it maps a different route, one starting with the original spirit of the modern portfolio theory and extending the concept of financial diversification to economic diversification – in the truest sense of the word, not at industry level, but in the measurement of the underlying economic activity creating 21st century prosperity and in its contribution to the long-term maximization of the public and private good.

The route mapped here represents the ideal articulated by Robert Frost (Frost and Lathem, 1969), who when looking back, concluded that:

“I shall be telling this with a sigh

Somewhere ages and ages hence:

Two roads diverged in a wood, and I—

I took the one less traveled by,

And that has made all the difference.”

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Annex I

The following summarizes the survey questions administered to institutional investors as part of the collection of feedback on the model, using Google Form.

1. Please describe your institution…

2. Please let us know where you are based…

3. How does the 2°C assessment framework compare to other 'climate assessments' you have done in terms of ability to integrate into investment decisions / portfolio management?

4. How likely would it be for you to use the assessment in your investment decisions or shareholder engagement processes?

5. How likely is it that you would use the assessment if available on a financial database platform as part of a portfolio optimisation tool?

6. Which of the following data points do you think would be most relevant for your use case?

    1. Data at portfolio level

    2. Data at aggregate company level

    3. Data at company level by region

    4. Data of all the assets owned by a company

7. What are the most relevant / most interesting aspects of the assessment?

8. What other types of results would you find the most interesting? (multiple answers possible)

9. Please briefly summarise, if applicable, how you have used the assessment to date or how you would potentially plant to use it in the future. What if anything is missing from the current assessment to allow this?

10. What are the biggest flaws / gaps in the 2°C assessment framework? What are the needed next steps to improve the test?

11. Please add any other comments you may have.

Jakob THOMÄ

OPTIMAL DIVERSIFICATION AND THE TRANSITION TO NET ZERO: A METHODOLOGICAL FRAMEWORK FOR MEASURING CLIMATE GOAL ALIGNMENT OF INVESTOR PORTFOLIOS

Résumé

La thèse développe un cadre qui permet aux décideurs politiques, aux investisseurs institutionnels, aux ONG et aux individus de mesurer l'alignement de leur portefeuille financier avec les objectifs climatiques. Le cadre met en relation l'activité économique sous-jacente aux portefeuilles financiers avec les actifs financiers et compare les tendances associées avec l'objectif climatique de 2 ° C. L'outil analytique sous-jacent répond à l'Accord de Paris et aux initiatives de politique internationale visant à aligner les marchés financiers sur les objectifs climatiques. Le cadre a été testé et appliqué par plus de 250 institutions financières, superviseurs financiers et ONG. Il aide les acteurs à intégrer les critères climatiques dans les décisions d'investissement, ainsi qu'à reconnecter les marchés financiers avec l'économie réelle dans le contexte de la transition vers une économie bas-carbone.

Mots clés

Changement climatique ; Théorie moderne de portefeuille ; Finance

Résumé en anglais

The thesis develops a framework that allows policymakers, institutional investors, NGOs, and individuals to measure the alignment of their financial portfolio with climate goals. The framework connects the economic activity underlying financial portfolios with financial assets and compares the associated trends with the 2°C climate goal. The underlying analytical tool responds to the Paris Agreement and international policy initiatives to align financial markets with climate goals. The framework has been tested and applied by over 250 financial institutions, financial supervisors, and NGOs. It helps actors integrate climate criteria into investment decisions, as well as reconnecting financial markets with the real economy in the context of the low-carbon transition.

Keywords:

Climate change; Modern Portfolio Theory; Finance