TEXTE
49/2018

System analysis for environmental policy – System thinking through system dynamic modelling and policy mixing as used in the SimRess project

Models, potential and long-term scenarios for resource efficiency (SimRess)

For our Environment

Umwelt Bundesamt

TEXTE 49/2018

Environmental Research of the
Federal Ministry for the
Environment, Nature Conservation
and Nuclear Safety

Project No. (FKZ) 3712 93 102
Report No. (UBA-FB) 002654/1,ENG

System analysis for environmental policy – System thinking through system dynamic modelling and policy mixing as used in the SimRess project

Models, potential and long-term scenarios for resource efficiency (SimRess) – Report 1

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On behalf of the German Environment Agency

Imprint

Publisher:
Umweltbundesamt
Wörlitzer Platz 1
06844 Dessau-Roßlau
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Study performed by:
Ecologic Institut
Pfalzburger Straße 43-44
10717 Berlin

Study completed in:
July 2017

Edited by:
Section I 1.1 Fundamental Aspects, Sustainability Strategies and Scenarios, Sustainable Resource Use
Ullrich Lorenz

Publication as pdf:
http://www.umweltbundesamt.de/publikationen
ISSN 1862-4804

Weitere Publikationen aus dem Forschungsvorhaben 3712 93 102:
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Dessau-Roßlau, June 2018

Kurzbeschreibung

Vielfältige Wechselbeziehungen und Multi-Akteurssyteme machen Ressourcennutzung zu einem komplexen System. Die Analyse komplexer Systeme kann helfen, Ressourcenpolitik langfristig und systemisch aufzustellen. Eine Systemanalyse erfordert systemisches Denken sowie die Berücksichtigung von Kausalketten, Feedbackschleifen und Zeitverzögerungen in Systemreaktionen.

Im Rahmen des SimRess-Projektes wurde die Systemanalyse durch eine partizipative Identifikation relevanter Systemgrenzen und -komponenten sowie der Diskussion möglicher politischer Interventionspunkte mittels Kausalschleifendiagrammen umgesetzt. Die Ergebnisse der Systemerarbeitung wurden dann soweit möglich in den Parametrisierungen der Simulationsmodelle zur integrierten Systemanalyse eingespeist und in der Gestaltung von Politikmixen zur Simulation berücksichtigt.

Für die partizipative Systemerarbeitung konnte nur eine begrenzte Anzahl an Akteuren zur Teilnahme an zwei der fünf Workshops gewonnen werden, die für einen kompletten Gruppenmodellierungsprozess notwendig sind. Daher wurde das partizipativ begonnene Systemmodel in mehreren projektinternen Workshops finalisiert und für die Verwendung in den Simulationsmodellen aufbereitet. Zwar wurden dadurch „Ownership“ und Transparenz des Models für externe Akteure verringert, allerdings konnten auch so relevante Systemerkenntnisse gewonnen und reflektiert werden.

Die Kausalschleifendiagramme dienten dann als Grundlage, um politische Interventionspunkte zu ermitteln und in Politikmixe zu überführen. Dabei wurde deutlich, dass die Erarbeitung von Politikmixen im Projekt vom theoretischen Konzept abweichen musste, um im Rahmen der Projektlogik weiterverfolgt werden zu können. Das bezog sich einerseits auf die Herausforderung, Politikmixe in ihrer kumulativen zukunftsgerichteten Wechselwirkung konzeptionell aufbereiten und bewerten zu können. Andererseits wurden in der Abstimmung mit externen Akteuren Entscheidungen getroffen, bestimmte Maßnahmenorientierungen vorzunehmen und bereits erarbeitete Mixe nicht weiter in der Systemanalyse zu verfolgen. Dadurch konnten insgesamt drei Politikmix-Ansätze ermittelt, aber nur in unterschiedlichem Umfang in die Systemanalyse mittels Simulationsmodellen einbezogen werden.

Abstract

Diverse and complex interactions as well as multi-actor systems characterise resource use and resource policy. This makes system analysis a relevant tool to orient resource policy towards the long term. Analysing such complex systems requires systemic thinking, consideration of causal loops as well as time-lags and delays in system responses.

In the SimRess project, system analysis encompassed participatory conceptual system modelling via involving external stakholders into identifying system boundaries and elements via causal loop diagrams (CLDs). The CLDs were than reflected in the parametrisation of simulation models and the development of policy mixes.

Only a limited number of stakeholders participated in two of the five workshops needed for a fully-fledged group modelling process. Therefore, the project team finalised internally the conceptual system model. Although this reduced ownership and transparency of the system model, the two workshops provided relevant system knowledge for further modelling work and policy mix development.

During policy mix development in SimRess, we needed to deviate from the theoretical concept of policy mixing based on available project capacities and stakeholder decisions. On the one hand, understanding and assessing cumulative effects of policy mixes challenged conceptual policy mix development and simulation capacities. On the other hand, stakeholder decisions impacted on the depth at which system analysis via simulation models could be undertaken.

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List of Abbreviations

BGR	Federal Institute for Geosciences and Natural Resources
CLD	Causal Loop Diagram
DENA	German Energy Agency
GMW	Group Modelling Workshop
MRIO	Multiregional Input-Output
NABU	Nature And Biodiversity Conservation Union
SD	System Dynamics
VCI	German chemical industry association
VDI	Association of German Engineers
VDMA	Mechanical Engineering Industry Association
WIOD	World Input Output Database (WIOD)

Zusammenfassung

Komplexe Interaktionen sowie Multi-Akteurs-Systeme charakterisieren Ressourcennutzung und Ressourcenpolitik. Für ein umfassendes Verständnis und eine vorausschauende Ressourcenpolitik ist es essenziell, die Schlüsseldynamiken und -charakteristiken im komplexen System der natürlichen Ressourcen aus verschiedenen Perspektiven (z.B. politisch, ökologisch, sozial, technologisch, rechtlich, ökonomisch) und sowohl auf nationaler, als auch auf internationaler Ebene zu analysieren. Ein systemischer Denkansatz erscheint hier nötig.

Modellierungsworkshops für Gruppen und Kausalschleifendiagramme

Durch die Erstellung konzeptueller Modellstrukturen – oft mithilfe von Kausalschleifendiagrammen (Causal Loop Diagrams, CLDs) beschäftigt sich die Systemanalyse mit der detaillierten Untersuchung von Systemen sowie von Interaktionen und Bestandteilen innerhalb und zwischen diesen Systemen. CLDs helfen bei der Identifizierung von Problemen und bei der Bildung eines konzeptuellen Modells eines dem System zugrundeliegenden Problems durch die Klärung kausaler Zusammenhänge und Interaktionen zwischen verschiedenen Systemelementen. Die Nutzung von CLDs als narrative Visualisierungswerkzeuge ist ein effektiver Weg, um Probleme und dessen Grundursachen sowie Alternativlösungen und mögliche Ansatzpunkte in dynamisch komplexen Systemen zu identifizieren, zu bewerten und zu kommunizieren. Ein zusammenhängendes Narrativ eines bestimmten Problems kann durch die gemeinsame Konzeptualisierung und Visualisierung verschiedener Elemente und dessen Zusammenhänge erzeugt werden. Es erleichtert somit die Analyse komplexer und dynamischer Systeme.

Im SimRess Projekt haben wir einen systemwissenschaftlich basierten Gruppenmodellierungsprozess als Teil der Modellierungsarbeit durchgeführt, welcher Interessengruppen mit einbezog. Der partizipative Gruppenmodellierungsprozess sollte ein transparenter und gemeinsamer Lernprozess sein, indem verschiedene Stakeholder die Chance hatten, Wissen und Erfahrungen innerhalb mehrerer Workshops auszutauschen. Diese Workshops zielten darauf ab:

1. Die Schlüsselsektoren / Schwerpunktbereiche für Ressourcenpolitik bzw. Sektoren mit Knappheitspotential in Deutschland zu identifizieren;
2. Ein systemisches Verständnis der Schlüsselelemente und dessen Schlüsselsektoren/ Schwerpunktbereichen zu entwickeln;
3. Konzeptuelle Sub-Modelle für die ausgewählten Schlüsselsektoren / Schwerpunktbereiche zu entwickeln;
4. Interventionspunkte für die Ressourcenpolitik für die Sektoren / Schwerpunktbereiche zu identifizieren und zu diskutieren.

Die Ergebnisse des Workshops sollten dann als Informationsgrundlage dienen, um die Systemrepräsentation im System Dynamics (SD) Modell WORLD weiterzuentwickeln und um potenziell relevante Interventionspunkte für Ressourcenpolitikmixe zu identifizieren.

Trotz umfassender Verfahren zur Identifikation und Einladung von Stakholdern zu den Workshops gab es Probleme damit, eine ausreichende Anzahl an Teilnehmenden für die Serie an Gruppenmodellierungsworkshops zu gewinnen. Daher wurde die Entscheidung getroffen, den partizipativen Workshop-Prozess nach den ersten beiden Workshops zu beenden. Plausible Begründungen für die geringe Teilnahme von Stakholdern könnten sein:

a) Mangelndes Interesse, mangelnde Zeit, mangelnde Kapazitäten
b) Sprachbarrieren, da der Workshop teilweise in englischer Sprache gehalten werden musste (aufgrund von internationalen Partnern im SimRess-Projekt)
c) Mögliche Enttäuschungen in früheren Workshops und / oder fehlender Sinn einer erneuten Diskussion größerer Fragen der Ressourceneffizienz in Workshops früherer Projekte

d) Informationsdefizite
e) Konstitutive Herausforderungen, welche die Angemessenheit des geplanten Gruppenmodellierungsprozesses hinterfragen.

Da der Gruppenmodellierungsprozess nach den ersten beiden Workshops abgebrochen wurde, beendeten wir die konzeptuellen Systemabbildungen in internen Projekt-Treffen unter Teilnahme von SimRess Projektpartnern und Vertretern des UBA. Bei diesen Projekt-Treffen wurden die folgenden vier Themenbereiche fokussiert: Bau / Infrastruktur; Konsum privater Haushalte; Beschäftigung; und die ökologischen Auswirkungen auf Ressourcennutzung im Allgemeinen. Darüber hinaus versuchten wir innerhalb eines weiteren Modellierungsworkshops einen Einblick in einen Teil der Struktur und Mechanismen der ökonometrischen, dynamischen MRIO Models GINFORS zu erlangen. Die Entwicklung eines sehr aggregierten CLD unterstützte die spätere Identifikation von Ansatzpunkten für die Politik. Die konzeptuellen Systemabbildungen und CLDs wurden dann genutzt, um die Systemdarstellung im systemdynamischen WORLD5 Modell zu erarbeiten und um den Parametrisierungsprozess des GINFORS Modells zu reflektieren.

Systemdynamische Modellierung mithilfe des WORLD5 Models

Systemdynamische (SD) Modellierung ist eine Methodik, die zur Analyse des Verhaltens von komplexen dynamischen Systemen über die Zeit genutzt wird. Es setzt sich mit internen Feedbackschleifen und Zeitverzögerungen auseinander, welche das Verhalten eines gesamten Systems beeinflussen. SD basiert auf dem Prinzip von Feedbackzusammenhängen zwischen den Bestandteilen/ Variablen des Systems, die das Systemverhalten bestimmen. Auch wenn die zugrundeliegende Grundstruktur des Systems dieselbe bleibt, verändern sich die einzelnen Bestandteile/ Variablen mit der Zeit; durch Feedbackschleifen beeinflusst die Veränderung eines Bestandteils/ einer Variable das Gesamtsystem und somit auch den Bestandteil/ die Variable selbst.

Basierend auf die konzeptuellen Modelle und CLDs baut der SD-Modellierungsprozess ein dynamisch-numerisches Modell mit relevanten vorhandenen Daten. Einer der zentralen Tests bezüglich der Struktur und des Verhaltens von SD Modellen ist die Sensitivitätsanalyse. Eine Sensitivitätsanalyse hilft dabei zu beobachten wie sensibel das Modellverhalten bei sich verändernden Werten von Modellkomponenten ist. Dies erlaubt die Identifizierung der sensibelsten Komponenten des Modells und der Komponenten mit dem größten Einfluss in unterschiedlichen Szenarien. Als finales Produkt dient das SD Modell als Tool zur Entscheidungshilfe, um Simulationen für alternative Szenarien mit unterschiedlichen Umsetzungszielen und –zwecke in einem Lernumfeld zu ermöglichen.

Das SD Modell WORLD5 läuft iterativ, um die komplexen Interaktionen zwischen Bevölkerung, Wirtschaft, Nahrungsmittelproduktion, Ökologie und Ressourcen über einen erweiterten Zeitraum und aggregiert auf globaler Ebene (d.h. alle Parameter als globale Summen oder Durchschnittswerte anstatt Unterschiede zwischen geografischen Regionen zu Modellieren) zu reflektieren. Das WORLD Modell besteht aus verschiedenen (Sub-) Modulen; vier dieser Module (Bevölkerung, Wirtschaft, Land/ Nahrung und Ökologie) sind identisch mit denen der letzten Instanz des WORLD3 Modells (Meadows et al.). Indem es das WORLD3 Modell in seiner Struktur aufnimmt und es mit einem detaillierteren Ressourcenmodul und einem neuen, einfachen Klimamodul verbessert, liefert das WORLD5 Modell detailliertere Simulationsergebnisse in Hinsicht auf das globale Angebot verschiedener Ressourcen, einschließlich Metalle1, Materialien (z.B. Phosphor, Gestein, Sand und Kies) und Energieträger (z.B. Öl,

[1] z.B. Bronze (Kupfer, Zink, Blei, Silber, Gold und die abhängigen Metalle Antimon, Wismut, Kobalt, Gallium, Geranium, Indium, Cadmium, Tellurium, Selenium), Stahl (Eisen

Kohle und Gas) und hinsichtlich des Energiekonsums, der mit der Nutzung dieser Ressourcen verbunden ist.

Aufgrund der Tatsache, dass die Gruppenmodellierungsworkshops nach dem zweiten Workshop beendet wurde, fokussierte sich die SD Modellierungsarbeit auf die weitere Entwicklung des WORLD Modells mithilfe der Erfahrungen aus den zwei durchgeführten Workshops. Diese halfen dabei, das Verständnis der Systemgrenzen, der Zusammenhänge und der Kausalitäten zwischen verschiedenen Elementen des modellierten Systems zu verstehen. Nichtsdestotrotz reduzierte das frühzeitige Ende der Workshops die „Ownership" der Teilnehmenden am Modell und seiner Ergebnisse und damit auch die Transparenz der Modellerstellung.

Integrierte Systemanalyse durch SD und ökonometrische Modellierung

Ein zentrales Alleinstellungsmerkmal des SimRess-Projektes ist die explizite Aufgabe, einen integrativen Modellierungsansatz zu diskutieren, welcher den SD Modellierungsansatz und Ergebnisse des WORLD5 Modells mit ökonometrischen Modellierungsansätzen und dazugehörenden Ergebnissen aus GINFORS integrieren könnte. Die beiden Modellierungsansätze, die aus unterschiedlichen Denkschulen stammen und in eher separaten Gemeinden weiterentwickelt wurden, haben beide sowohl eine spezifische Simulations- und Aussagekraft als auch individuelle Stärken und Schwächen.

Da das WORLD5 Modell das WORLD3 Modell in seiner Struktur übernimmt, erlebt es auch dieselbe wissenschaftliche Kritik in Bezug auf Verlässlichkeit der Methodik und der Daten (z.B. Mangel an ausreichend validen empirischen Daten) angesichts des Zwecks, für den das WORLD3 Model konzipiert wurde: die Evaluierung von Verhaltensmustern von den folgenden Schlüsselvariablen: Bevölkerung, Industrieproduktion, Lebensmittel, Umweltverschmutzung und nicht-erneuerbare Ressourcen.

Es ist erstaunlich, dass die Ergebnisse eines dynamischen multi-regionalen ökonomischen Simulationsmodells nicht bereits zuvor in die Analyse globaler sozio-ökonomischer Wechselbeziehungen in WORLD3 inkorporiert wurde, sowie es im SimRess Projekt angestrebt wurde.

Das dynamische ökonometrische Simulationsmodell GINFORS3 entspringt etablierten ökonomischen Theorien und wird anhand von empirischen Falsifizierungstests evaluiert. Auf Grund der häufigen Nutzung von regressionsbasierten ökonometrischen Methoden zur Selektion und Spezifikation von Verhaltensgleichungen wird es auch manchmal als „ökonometrisches Modell" bezeichnet. Angewandte ökonometrische Analysen bauen ihrerseits auch auf konzeptionellen Modellen auf, um aussagekräftige numerische Modelle zu implementieren. Wenn der Modellierungsprozess außerdem mit einer qualitativen CLD-basierten Systemanalyse beginnt, könnten Modellierer, Auftraggeber und Akteure motiviert werden für den zu bearbeitenden Problemfall zusätzliche qualitative Erkenntnisse, die der traditionelle ökonometrische Ansatz nicht zulässt, zu generieren. Aus ökonometrischer Sicht können kausale Einflüsse jedoch nur robust quantifiziert werden, wenn sie in einem „Reale-Welt-System" einsehbar sind: die Quantifizierung von dynamischen numerischen Simulationsmodellen sollte deshalb immer erfragen, ob eine Quantifizierung den Wert der darauffolgenden Simulationsergebnisse erhöhen würde. Die dynamischen Eigenschaften von parametrisierten Simulationsmodellen können nicht aus einer isolierten Sichtweise bezüglich inkorporierter Kausalitäten bewertet werden. Deshalb können Schlussfolgerungen über die quantitativen Schlüsseleigenschaften des Models nicht eindeutig von der alleinigen Inspektion von qualitativen CLDs abgeleitet werden. Es ist zwar möglich eine (nicht-evaluierbare) Experten-Schätzung anstelle von empirisch abgeschätzten Parametern anzuwenden, doch verbleibt die Übersetzung von qualitativer Information in numerische Parametrisierungen von CLDs damit weniger transparent in der Diskretion der Modellierer, wenn dem CLD keine zusätzlichen Informationen transparent hinzugefügt werden. Die Folge ist eine Art Arbitrarität zwischen dem endgültig parametrisierten Simulationsmodell und dem partizipatorisch etablierten qualitativen CLD des Gruppenmodellierungsworkshops.

Es wird hierbei unterstrichen, dass die Entscheidung zur Quantifizierung von konzeptionellen Modellen von zusätzlichen Dokumenten begleitet werden sollte, die ausreichend Informationen zu dynamischen Eigenschaften parametrisierter Modelle bereitstellen und das quantifizierte Modell ausreichend validieren. Deshalb empfehlen wir, die implizierten Annahmen von Großmodellen im Vergleich mit den Ergebnissen verschiedener kontrollierten Simulationsexperimenten zu bewerten.

Über die Reflexion von modellspezifischen Stärken und Schwächen hinaus, hat das gegenseitige Lernen zwischen SD-Modellierern und ökonometrischen Modellierern im Verlauf des SimRess Projekts Erkenntnisse zur Verbesserung von Informationsflüssen zwischen den Modellierungsansätzen geliefert. Weiterhin hat der Modellaustausch auch die Reflexion zur Frage vorangetrieben, wie sich die beiden unterschiedlichen Modell(ansätz)e am besten für eine robustere Systemanalyse ergänzen können.

GINFORS3 wurde innerhalb SimRess angewandt, um die globale Wirtschaftsentwicklung bis 2050 festzustellen. Um eine detaillierte Projektion der globalen Rohstoffförderung abzuleiten, wurden aggregierte Nachfragedaten von GINFORS3 in WORLD eingegeben. Dieser Informationsaustausch hat dazu geführt, dass das Projektteam endogene Projektionen zu globalen Metallerzpreisen produziert hat: Üblicherweise repräsentierten diese Wachstumszahlen eine der wenigen exogenen Modellvariablen in GINFORS3. Diese Preisdynamiken sind jedoch endogen von den Angebotsdynamiken in WORLD5 berechnet worden. In einer iterativen „Soft-Link“ Herangehensweise haben gepaarte Simulationsübungen die Umsetzbarkeit von integrierten Projektionen zu Weltmarktpreisen bewiesen, welche die globalen Angebots- und Nachfragedynamiken berücksichtigen. Die Kombination von Methoden, z.B. Angebotsdaten aus SD-Modellen und Nachfragedaten aus ökonometrischen Modellen, ist eine offensichtliche Variante für die Analyse von globalen Ressourcenflüssen. Aufgrund der bestehenden weitreichenden internationalen Datenzusammenstellung und -harmonisierung verfügen ökonomische Modellierungsansätzen heutzutage über eine sehr gute Datengrundlage (wie bei GINFORS). Deshalb sollten dynamische Simulation von ökonomischen Entwicklungen diese verfügbaren Strukturen einbinden (z.B. sollte globale ökonomische Entwicklung von Modellen wie GINFORS simuliert werden). Im Vergleich zu diesen harmonisierten Datensätzen ist die Verfügbarkeit von zuverlässigen Daten eventuell nicht ausreichend, um einen ökonomischen Ansatz bei dynamischen Angebotsprojektionen durchzuführen. Deswegen müssen hierzu zusätzliche Methoden hinzugezogen werden.

Der „Soft-Link“ zeigt, dass die SD-basierten Angebotsprojektionen von ökonomischen Nachfrageprojektionen angetrieben werden können, welche nicht der bestehenden Kritik gegenüber der von Meadows et al. entwickelten WORLD3-Modellen ausgesetzt sind. Aus akademischer Sichtweise bleibt es interessant zu betrachten, wie sich die ökonomischen Projektionen des „Soft-linked Modelling Framework“ mit den WORLD3 Modellprojektionen vergleichen lassen und was dies für die post-2050 Ergebnisse aus WORLD bedeutet.

„Policy Mixing“ als systemischer Ansatz für politische Entscheidungsprozesse – Konzept und Herausforderungen

Das Konzept des „Policy Mixing“ ist ein systemischer Ansatz für das Management von komplexen Systemen und für die Förderung des Wandels zur nachhaltigen Ressourcennutzung. Politikmixe im Sinne von Instrumenten-Mixen werden in verschiedenen umweltpolitischen Kontexten angewandt. Bei Politikmixen wird jedoch meist einfach neue bzw. weitere politische Instrumente hinzugefügt, ohne die potentielle Interaktion und die langfristige Kohärenz des Politikmixes zu betrachten. Das kann zu Zielkonflikten zwischen verschiedenen Instrumenten beitragen und die allgemeine Wirksamkeit des Politikmixes reduzieren.

Im Gegensatz dazu dient das theoretische Politikmix-Konzept als Heuristik, welche Politikdesign, Bewertung des Mixes und Vorbereitung zur Implementierung unterstützen helfen soll. Diese Heuristik beruht auf verschiedenen auf einander aufbauenden Schritten:

1. Die Zielsetzung und konkrete Zwischenziele des Mixes festlegen;

2. Die Treiber und Grenzen des Systems bzw. der Problemstellungen identifizieren, die vom Mix angesprochen werden sollen;
3. Relevante politische Instrumente auswählen, die anhand von ex-ante Bewertungen das Potential haben, die Zielsetzung des Mixes zu erreichen;
4. Instrumente so kombinieren, dass Synergien gefördert und Konflikte bzw. negative Effekte minimiert werden
5. Den endgültigen Policy Mix für die Durchführung vorbereiten, umsetzen und einem Monitoring unterziehen.

In diesem Kontext sollte der Designprozess eines Politikmixes darauf abzielen, (i) Konsistenz zwischen politischen Zielen und Instrumenten herzustellen sowie (ii) Kohärenz zwischen Prozessen, die für die Umsetzung des Mixes nötig sind, in den Blick zu nehmen. Über die Interaktion von Instrumenten hinaus ist die Kohärenz zwischen verschiedenen politischen Entscheidungen und administrativen Ebenen wichtig, um den Politikmix und seine Umsetzung soweit wie möglich in die institutionellen Konstellationen einzubetten. Somit geht das Design eines Politikmix weit über das lose Kombinieren von politischen Zielen und Instrumenten hinaus.

Dazu ist ein zukunftsorientierter „Roadmapping"-Prozess erforderlich, bei dem verschiedene politische Instrumente miteinander in einer zeitlichen Sequenz verbunden werden, welches Synergieeffekte maximiert und ungewollte negative Nebeneffekten minimiert. Hinzu kommt die Berücksichtigung von politischen Prozessen in einem polyzentrischen Governance-System, um eine langfristige Unterstützung verschiedener Akteuren zu sichern und den Mix tatsächlich adaptiv umsetzen zu können. In diesem Zusammenhang tritt das theoretische Politikmix-Konzept mit realen politischen Praktiken sowie mit den Dynamiken und Pfadabhängigkeiten von Legislaturperioden in Konflikt.

Des Weiteren erfordert das Politikmix Konzept, das wissenschaftliche Bewertungsergebnisse während der Entwicklung von Politikmixen berücksichtigt wird. Dies erweist sich aus mehreren Gründen als schwierig: (1) die konzeptionelle und auch robuste modelltechnische Bewertung kumulierten Auswirkungen von in einem Mix zeitlich aufeinanderfolgend kombinierten Instrumenten ist eine Herausforderung. (2) Damit zusammenhängend unterliegen wissenschaftliche Ergebnisse immer einem gewissen Grad der Unsicherheit, welche nach den Regeln der guten Praxis transparent kommuniziert werden sollten; politische Entscheidungen hingegen erfordern einen hohen Grad an Genauigkeit und Eindeutigkeit, welche ihnen die wissenschaftlichen Ergebnisse so häufig nicht liefern können. (3) Politische Entscheidungen für Ziele und auch für das Design politischer Instrumente müssen letztlich demokratisch legitimiert sein. Dabei müssen politische Entscheidungsträger verschiedene Wissensquellen und Optionen gegeneinander abwägen und auf politische und sozioökonomische Umsetzbarkeit prüfen. Dieser Prozess bedarf die Fähigkeit und Kapazität langfristige potentielle Auswirkungen mitzudenken, welche oft auf unsicheren wissenschaftlichen Erkenntnissen beruhen. Die bestehende politische Ökonomie, welche auf eine Machterhaltung für kommende Legislaturperioden ausgerichtet ist, belohnt Kurzfristigkeit und sofortigen Nutzen und entmutigt dabei langfristiges Denken mit zeitlich verlagertem Nutzen.

Deshalb ist das Design, die Implementierung und die Bewertung von Politikmixen zwar bereits eine wissenschaftliche Herausforderung, noch mehr jedoch eine der praktischen Umsetzung in einem bestehenden politischen Rahmen.

Politikmix-Konzept und Entwicklung in SimRess

Das SimRess Projekt hat das Politikmix-Konzept angewandt, um ressourcenpolitische Politikmixe zu entwickeln und mittels zweier Simulationsmodelle zu bewerten – ohne sich auf die mögliche Vorbereitung der Implementierung der Mixe konzentrieren zu können. Der wissenschaftliche Fokus lag dabei zwar auf nationaler Ressourcenpolitik, doch wurde durch die Berücksichtigung von internationalen Wertschöpfungsketten und Handelsströmen auch die europäische Ressourcenpolitik mit einbezogen. Folglich wurden die Effekte von internationalen Trends und politischem Handeln auf die deutsche Ressourcenpolitik und umgekehrt auf systemische Weise berücksichtigt.

Es wurden während des SimRess Projekts drei verschiedene Politikmix-Ansätze entwickelt:

1. Ein systemischer ressourcenbezogener Politikmix-Ansatz bezüglich relevanter Treiber und Trends nicht nachhaltiger Ressourcennutzung
2. Ein ressourcenbezogener Politikmix-Ansatz, der auf bestimmten ProgRess II Instrumenten beruht
3. Ein systemischer ressourcenbezogener Politikmix-Ansatz der darauf abzielt, ambitioniertere und längerfristige ressourcenpolitische Ziele zu unterstützen

Die verschiedenen Ansätze sind unterschiedlich detailliert. Stakeholder-Feedback im Projektverlauf hat im Lichte der im Forschungsprojekt verfügbaren Kapazitäten veranlasst, dass nur die ersten drei iterativen Schritte der Heuristik (einschließlich ex-ante Bewertung) für die Politikmix-Ansätze 2. und 3. entwickelt wurden. Der erste Politikmix wurde im Rahmen der derzeitigen Ressourcenpolitik von ProgRess II als weniger relevant eingestuft und deshalb nicht in die ex-ante Bewertungen eingebunden. Für alle drei Politikmix-Ansätze haben wir Folgendes beschrieben:

a) Die Zielsetzungen;
b) Das unterliegende konzeptionelle kausale Systemmodell;
c) Die Auswahl der Instrumente des Mixes
d) Die wissenschaftliche ex-ante Bewertung der potentiellen Effekte der Mixe (dieser Teil ist ausführlich im Bericht zur Dokumentation des Modells GINFORS enthalten).

Während das zugrundeliegende konzeptionelle und kausale Systemmodell für die Politikmix-Ansätze 1. und 2. ähnlich ist, wurde der dritte Ansatz entwickelt, um ambitionierte ressourcenpolitische Ziele in den Blick zu nehmen, die nicht Teil der offiziellen ressourcenpolitischen Dokumente Deutschlands sind. Die Auswahl der Instrumente unterscheidet sich in den drei Ansätzen:

1. Der systemische ressourcenbezogene Politikmix-Ansatz bezüglich relevanter Treiber und Trends nicht nachhaltiger Ressourcennutzung beinhaltet drei unterschiedliche instrumentelle Schwerpunktsetzungen: (i) Unterstützung nachhaltiger Produktion durch die Schaffung von Anreizen für nachhaltige Konsumentenentscheidungen und die Verbesserung der Verfügbarkeit – und Bezahlbarkeit – von nachhaltigen Produkten und Dienstleistungen; (ii) Förderung nachhaltiger Produktion durch die Schaffung finanzieller Anreize für eine nachhaltige Produktion und nachhaltige Produkte sowie internationaler Normen für nachhaltige Produkte; und (iii) absolute Reduktion von Ressourcennutzung mittels Zertifikathandel und festen Obergrenzen für Materialien auf Privathaushaltsebene;
2. Der ressourcenbezogene Politikmix-Ansatz, der auf bestimmten ProgRess II Instrumenten beruht, umfasst alle Phasen der Wertschöpfungskette: (i) Sicherstellung nachhaltiger Rohstofflieferungen durch die umweltfreundliche Nutzung von Biomasse; (ii) Erhöhung der Ressourceneffizienz in der Produktion durch die Fortsetzung und Erweiterung von Finanzierungsprogrammen für material- und energieeffiziente Technologien und Prozesse sowie die landesweite Erweiterung der Ressourceneffizienz-Beratung; (iii) Erreichung eines ressourceneffizienten Konsums durch Standards für Ressourceneffizienz und erhöhte Produktvielfalt in der Kategorie „Ressourcenschonend“ des

Blauen Engels. Zusätzlich wurde die Verwendung übergreifender Instrumente über die Finanzierung von Forschungsprojekten zu ressourceneffizienten, integrierten Lösungen für Planung, Entwurf, Konstruktion und Modernisierung sowie, wenn machbar, Demontage von veralteten Strukturen und Rückgewinnung von Baumaterial für das Recycling und die Wiederverwertung berücksichtigt;

3. Im Gegensatz zu den ersten beiden Politikmix-Ansätzen haben wir einen anderen Ansatz für den Entwurf einer systemischen Ressourcenstrategie gewählt, die darauf abzielt, einen Beitrag zu ambitionierteren, langfristigeren strategischen Ressourcenzielen zu leisten. Die Vielfalt der Veränderungen in den Sektoren, die ausweislich der Modellsimulation ermöglichte, die für diesen Mix festgelegten Ziele zu erreichen, erlaubte lediglich die Ableitung systemischer Ansatzpunkte auf höher aggregierter Ebene: Strategien, die (i) sich auf die Reduzierung von primärem Input und die Unterstützung der sekundären Materialverwendung konzentrieren; und (ii) den Mut besitzen, Änderungen des Lebensstils und strukturelle Veränderungen durch die Belohnung dieser Veränderungen und die Bestrafung eines fehlenden Veränderungswillens anzusprechen, während die negativen Folgen für Verlierer weitestgehend minimiert werden sollen.

Die ex-ante Bewertung der Politikmix-Ansätze 2. und 3. wurde mittels des Modells GINFORS vorgenommen. Die Bewertungen konzentrierten sich auf die potentiellen wirtschaftlichen und ökologischen Auswirkungen der einzelnen Instrumente.

Erkenntnisse aus der Entwicklung und Bewertung der Politikmix-Ansätze in SimRess:

Das SimRess-Projekt bot die Möglichkeit, die wissenschaftliche Entwicklung und ex-ante Bewertung von Politikmixen kritisch zu beleuchten. Während wir die ersten drei aufeinanderfolgenden Schritte im heuristischen Politikmix-Konzept anwenden konnten, haben wir festgestellt, dass die konzeptionelle Entwicklung der Politikmixe beschränkt ist:

1. durch Entscheidungen von Stakeholdern und auch im Projektmanagement, die konzeptionelle Weiterentwicklung und ex-ante Bewertung des systemischen ressourcenbezogenen Politikmix-Ansatz bezüglich relevanter Treiber und Trends nicht nachhaltiger Ressourcennutzung nicht weiterzuverfolgen;
2. auf eine Kombination von Instrumenten gemäß ProgRess II. Diese wurden weder auf Konsistenz geprüft, noch in einer zeitdynamischen, sequentiellen Methode kombiniert, in der festgelegt wird, welche(s) Instrument(e) zuerst, welche später und in welcher Reihenfolge an der Reihe sind;
3. auf eine modell-experimentelle Nachkonstruktion von Veränderungen in Sektoren, die darauf abzielt, einen Beitrag zu ambitionierteren, langfristigeren strategischen Ressourcenzielen zu leisten, die wir nicht in explizite Vorschläge für Politikinstrumente weiterentwickeln konnten.

Daher empfanden wir es als eine der wesentlichen Herausforderungen, Input sowohl aus der Wissenschaft als auch von Stakeholdern in die Entwicklung der Politikmix-Ansätze zu integrieren. Das führte zu einer Neuorientierung der verfügbaren Kapazitäten im SimRess-Projekt auf (i) die Untersuchung einer kleinen Auswahl an ProgRess II-Instrumenten, bei der anhand des Feedbacks relevanter ProgRess II-Stakeholder davon ausgegangen wurde, dass sie auf eine breitere Unterstützung in der Bevölkerung und bei Interessenvertretungen stoßen würde; (ii) einen Politikmix, der darauf abzielt, einen Beitrag zu ambitionierteren, langfristigeren strategischen Ressourcenzielen zu leisten, bei der noch eine breitere Diskussion in der Bevölkerung zur Notwendigkeit und Machbarkeit geführt werden muss.

Aufgrund der spezifischen Kapazitäten des SimRess-Projekts und von Stakeholderfeedback waren wir lediglich in der Lage, einen kleinen Teil der bestehenden und potentiell denkbaren und vielversprechenden Instrumente in SimRess zu beurteilen. Dies mag aus Sicht der wissenschaftlichen Fragestellung vielleicht enttäuschend sein, aber es ist wichtig, den Dialog zwischen wissenschaftlichen Beweisen und Politikentwicklung offen zu halten und der Wissenschaft zu praktischen Anwendungen zu verhelfen. Und nur durch diesen Austausch zwischen Wissenschaft und Politik können die demokratische Legitimation der (Ressourcen-)Politikentwicklung aufrechterhalten und die unnötige Abgabe der Verantwortung an die Wissenschaft zurückgewiesen werden, eine Patentlösung ohne politische Verhandlungen entwickeln zu müssen.

Eine weitere Herausforderung war die wissenschaftliche, modellbasierte Bewertung der Politikmix-Ansätze. Die quantitative, modellbasierte Beurteilung beschränkte sich auf:

- die Beurteilung einzelner Instrumente ohne Berücksichtigung ihrer möglicherweise kumulativen Auswirkungen (Synergien oder Interaktionen);
- die Beurteilung möglicher Auswirkungen von Veränderungen in der Nachfrage von ressourcenrelevanten Sektoren hin zur Zielerreichung ohne die Ableitung konkreter politischer Instrumente, welche diese Veränderungen bewirken könnten.

Während die Entwicklung eines Politikmixes als Teil eines Forschungsprojekts zu wissenschaftlichen ex-ante Bewertungen führen kann, die für die Neuentwicklung eines Politikmixes relevant sind, wird dieser Prozess erschwert durch:

1. die inhärente Schwierigkeit, die kumulative Wirksamkeit einer Kombination von Instrumenten mit der von Einzelinstrumenten zu vergleichen; dies bleibt eine methodologische Herausforderung, die weiter untersucht werden muss. Darüber hinaus könnte die spezifische Modellierungslogik des verwendeten GINFORS-Simulationsmodells die Fähigkeit einschränken, einige Instrumente oder Instrumentenentwürfe, die zu systemischen Veränderungen führen könnten, zu modellieren – eine solche Beurteilung fiel nicht unter die Forschungsaufgaben im Rahmen des SimRess-Projekts und müsste näher analysiert werden;
2. die logische Lücke zwischen einer wissenschaftlichen ex-ante Bewertung der potentiellen Wirksamkeit eines Politikmixes und ihrer tatsächlichen Umsetzung im realen Umfeld, wodurch sich zwangsläufig die Art oder das Design – und damit die potentiellen Auswirkungen – des Politikmixes ändern.

Die Entwicklung konsistenter und kohärenter Politikmixe kann zu einer systemischeren und möglicherweise effizienteren Politikgestaltung beitragen. Jedoch können weder wissenschaftliche Konzeptualisierungen von Politikmixen noch ex-ante Bewertungen politische Prozesse vorhersehen, die Auswirkungen auf die letztendliche Gestaltung der Mixe und auf ihre Umsetzung haben.

Obwohl es sich um ein vielversprechendes Konzept zur Verbesserung des Systemdenkens und langfristiger Ansätze in der Ressourcenpolitik handelt, bestehen beim Design von Politikmixen große Herausforderungen, die besser analysiert werden müssen, um die Anwendbarkeit von Politikmixen für eine langfristige Ressourcenpolitik zu erhöhen.

Schlussfolgerungen

Die Systemanalyse scheint für die Unterstützung zukunftsorientierter und systemischer Ressourcenpolitik gut gerüstet zu sein. Durch langfristige ex-ante Bewertungen, die sich auf SD-Modelle stützen, können Zeiträume betrachtet werden, die über die herkömmliche Abdeckung von Simulationsmodellen für die Politikberatung (in der Regel bis 2050) hinausgehen – damit können Zeitverzögerungen und Feedbacks, die sonst unbemerkt bleiben würden, identifiziert werden.

Mittels der gemeinsamen Sprache der CLDs können unterschiedliche Akteure sinnvoll miteinander in Austausch treten, um ein System zu verstehen und gemeinsam Lösungen im fraglichen System zu entwickeln. Wie jedoch die Erfahrung mit dem SimRess-Projekt gezeigt hat, gibt es viele Herausforderungen, die eine erfolgreiche Partizipation erschweren und die Verwendung der Beteiligungsergebnisse in den Simulationsprozessen infrage stellen können.

Die Diskussion eines integralen Modellierungsrahmens erweist sich aufgrund der beiden Modellierungssysteme mit unterschiedlichen zugrundeliegenden Paradigmen als schwierig. Der Austausch führte zu einer Informations-seitigen Verknüpfung zwischen den beiden Modellen, es wurde jedoch auch unterstrichen, dass sich die Modelle in vielerlei Hinsicht aus gutem Grund unterscheiden und dass mehr solcher Austausch zwischen unterschiedlichen Modellen nötig ist.

Das Politikmix-Konzept erscheint für die Systemanalyse passend, da es auf den CLDs aufbauen konnte, die für die Identifizierung generischer Interventionspunkte entworfen wurden. Jedoch lenkten die Projektkapazitäten und Stakeholderfeedback den Prozess der Politikmix-Entwicklung in eine bestimmte Richtung, die es uns nicht erlaubte, einen vollständig ausgereiften Politikmix-Designprozess durchzuführen. Wir sind der Meinung, dass das Konzept der Politikmix die Systemanalyse grundsätzlich sehr gut ergänzt, jedoch ist das Konzept in der Anwendung herausfordernd – in wissenschaftlichen ex-ante Bewertungen aufgrund der Schwierigkeiten, kumulative Auswirkungen verschiedener Instrumente, die sequentiell über die Zeit miteinander verbunden sind zu bewerten; und mehr noch bei der tatsächlichen Politikgestaltung und -umsetzung, da politische Realitäten und Erfahrungen zu den Fähigkeiten für langfristige Koalitionen im Gegensatz zu stehen scheinen.

Summary

Diverse and complex interactions as well as multi-actor systems characterise resource use and resource policy. For a comprehensive understanding of such issues on resource policy, it is essential to analyse key dynamics and conditions in the complex natural resources system from many different aspects (i.e. political, environmental, social, technological, legal, institutional, economic), and from national to global levels. Only a systems thinking approach can provide a sufficient understanding of what new arrangements are needed to develop policy that links to other policies from a wide range of policy areas and sectors across value chains.

Group modelling workshops and causal loop diagrams

Systems analysis deals with detailed examination of systems and the interactions of elements within and between such systems by creating conceptual model structures – often with the help of causal loop diagrams (CLDs), which ideally are elaborated in a group modelling process. CLDs help to identify a problem and build a conceptual model of a system underlying a given problem by clarifying the cause and effect relationships and the feedbacks between different system elements. The use of CLDs as narrative visualisation tool is an effective way to identify, assess and communicate problems, their major root causes, associated symptoms, as well as the alternative solutions and the possible leverage points in dynamic complex systems. Jointly conceptualising and visualising the different elements and their interconnections can create a coherent story about a particular problem or issue and hence facilitates systems analysis of complex and dynamic systems.

In the SimRess project, we undertook a systems science based and participatory stakeholder group modelling process as a part of the project's modelling work. The participatory group modelling process was meant to be a transparent and mutual learning process, where stakeholders would have the chance to exchange knowledge and experiences in a series of workshops. These workshops aimed at:

1. identifying key sector(s)/focus area(s) in Germany for resource policy or with scarcity potential;
2. developing a systemic understanding of the key elements of these key sector(s)/focus area(s);
3. developing conceptual sub-models for the selected key sector(s)/focus area(s);
4. identifying and discussing intervention points for resource policy for the sector(s)/focus area(s).

The workshop findings should then serve as information to further develop the system representation in the system dynamics model WORLD3, as well as to identify potentially relevant intervention points for resource policy mixes.

Despite a comprehensive stakeholder identification and invitation management procedures, we experienced problems in securing a sufficient number of stakeholder representatives to participate to the series of group modelling workshops. Due to fading stakeholder commitment, we decided to end the participatory workshop process after the first two workshops. Among other, some of the plausible reasons for low response and participation rates could be:

a) Lack of interest, time and personnel/capacities
b) Language barriers, as the workshops partially had to be held in English (due to the international partners in the SimRess project)
c) Possible earlier dissatisfaction in previous workshops and/or fatigue of discussing larger question of resource efficiency in workshops of previous projects
d) Lack of information
e) Constitutive challenges questioning the appropriateness of the planned group modelling process.

As the stakeholder participatory group modelling process was terminated after the first two workshops, we finalised the conceptual system maps in internal meetings with the participation of SimRess

project partners and representatives from UBA, focusing on four thematic areas: construction/infrastructure; private household consumption; employment; and the environmental impacts of resource use in general. Furthermore, during another internal group modelling workshop, we attempted to gain an insight of one part of the structure and mechanisms of the econometric, dynamic environmentally extended MRIO model GINFORS. Developing a very aggregated CLD supported later identification of policy leverage points (places to intervene in a system). The conceptual system maps and CLDs were then used to set-up the system representation in the system dynamic WORLD5 model, and was also reflected in the parametrisation process of the GINFORS model.

System dynamic modelling using the WORLD5 model

System dynamics (SD) modelling is a methodology used to understand the behaviour of complex dynamic systems over time. It deals with internal feedback loops and time delays that affect the behaviour of the entire system. SD is based on the principle of feedback relationships between the elements/variables of the system determining system behaviour. Even though the underlying basic structure of the system remains the same, the individual elements/variables change over time; through feedback loops, a change in one element/variable affects the overall system and in turn the element/variable itself.

Based on the conceptual models and CLDs, the SD modelling process then builds a dynamic numerical model with relevant available data. Following the model formulation with relevant data, the model is then validated by different means. In SD modelling one of several central tests regarding the structure and the behaviour of the model is sensitivity analysis. A sensitivity analysis helps to see how sensitive the model behaviour is to changing values of the model components. This allows identifying the components, which are most sensible in the model and have the biggest impact under certain scenarios. A sensitivity analysis also makes it possible to see whether the model behaviour is mostly sensitive to the magnitude of the components or mostly sensitive to the structure, as such the way the components are related to each other. As an end product, the SD model serves as a decision support tool to generate simulations for alternative scenarios with different implementation goals and objectives in a learning environment.

The SD model WORLD5 runs iteratively to reflect the complex interactions between population, economy, food production, ecology and resources over an extended time span and aggregated to a global level, i.e. all the parameters are global totals or averages, rather than modelling any differentiations between geographies. The WORLD model consists of several (sub-) modules, four of which (population, economy, land/food, and ecology) are identical to the ones presented in the latest instance of the WORLD3 Model (by Meadows et al.). Incorporating WORLD3 model in its structure, and enhancing it with a more detailed resources module and an additional simple climate module, the WORLD5 model provides more detailed simulation results on the global supply of various resources, including metals[2], materials (i.e. phosphorous, stone, sand, gravel) and energy sources (i.e. oil, coal, and gas), as well as on the energy consumption associated to extraction of these resources.

As planned stakeholder participatory group modelling workshops were cancelled after the second workshop, the SD modelling work focused on the further development of the WORLD model based on the learnings from the two workshops, which helped to improve understanding of system boundaries,

[2] I.e. BRONZE (Copper, Zinc, Lead, Silver, Gold and the dependent metals Antimony, Bismuth, Cobalt, Gallium, Germanium, Indium, Cadmium, Tellurium, Selenium), STEEL (Iron, Chromium, Manganese, Nickel, stainless steel), LIGHT METALS (Aluminium, Lithium), SPECIALTY METALS (Platinum group metals, Molybdenum, Rhenium, Niobium, Tantalum, Tin, Rare Earth Metals).

interlinkages and causalities between different elements of the system modelled. However, the cancellation reduced ownership of the model and its findings among and transparency towards external stakeholders.

Integrated system analysis through SD and econometric modelling

One central feature making the SimRess project stand out from other similar research projects was the explicit task of discussing and exploring options for a modelling framework that could integrate SD modelling approach and results from the WORLD5 model with econometric modelling approaches and associated results from the econometric, dynamic environmentally extended MRIO model GINFORS. Originating from different schools of thoughts and further developed in rather separate communities, both modelling approaches have their specific simulation and explanatory power, as well as strengths and limitations.

As the WORLD5 model adopts the WORLD3 model in its structure, it also needs to deal with scientific critique in terms of the reliability of methodology and the data (e.g. a lack of sufficient empirical data) in the face of the purpose the WORLD3 model was designed for: evaluating pattern of behavior of key variables, namely population, industrial output, food, pollution and non-renewable resources. It seems quite remarkable that there has not been any previous attempt to incorporate the outcomes from a state of the art dynamic Multi Regional economic simulation model in WORLD3's applied mapping of global socio-economic interrelationships as was attempted in the SimRess project.

The dynamic economic simulation model GINFORS3 is rooted within well-established economic theories and evaluated by thorough empirical falsification tests. Due to the prominent role of regression-based econometric methods for the selection and specification of its behavioral equations it is sometimes called an "econometric" model. While applied econometric analyses usually do not initiate from a visualization of underlying qualitative conceptual models, they rather rest on effectually reduced conceptual models in order to achieve a meaningful numerical model implementation. Supplemental efforts to start a modelling process with a qualitative CLD-based system analysis might certainly enable modelers, clients and stakeholders to generate additional qualitative insights into the problem under inspection which would not be uncovered by a traditional econometric approach. However, from an econometric point of view, causal influences can only be robustly quantified when they are observable within the real-world system: hence, quantifying a dynamic numerical simulation model should always ask whether their quantification might enhance the value for the later simulation outcomes. The dynamic properties of a parametrised simulation model cannot be assessed from an isolated view on the incorporated causalities. Therefore, conclusions about key quantitative features of the model cannot be unambiguously derived from sole inspections of qualitative CLDs. While it is possible to imply some kind of (non-evaluable) "expert guess" in place of empirically estimated parameters, the transfer of qualitative information from a CLD into numerical parametrisations are subject to the group of modelers' discretion only, if no supplemental information is transparently added to a CLD. This produces some kind of arbitrariness between the finally parametrised simulation model and the participatory established qualitative CLD from group modelling workshops.

This highlights that the decision to quantify conceptual models should be accompanied by additional meaningful documentations which provide sufficient information about the implied dynamic features of the parametrised model and help to sufficiently validate the quantified model. As these large scaled models exist to provide consistent mappings of complex and interrelated system responses to discrete variations of selected variables over time, we recommend assessing the implied assumptions of large scaled models by a comparison of findings from several controlled simulation experiments.

Beyond this reflection of model specific strengths and limitations, the mutual learning process between system dynamics modelers and econometric modelers over the course of the SimRess projects enabled us to draw some lessons learnt on improving information flows between the two modelling approaches as well as to reflect on how the two models could best complement each other towards more robust system analysis.

In SimRess, GINFORS3 was applied to generate global outlooks on overall economic performance until 2050. Aggregated demand figures were then fed from GINFORS3 into WORLD in order to derive detailed projections of global extraction activities. This exchange of information enabled the project team to produce endogenous projections of global metal ore prices: Usually, these price trajectories represent one of the few exogenous model variables in GINFORS3. These price dynamics are however endogenously derived from supply side dynamics in WORLD5. Thus, in an iterative soft-link procedure, coupled simulation exercises proved the feasibility of integrated world market price projections featuring a balanced consideration of global supply and demand dynamics. This combination of methodologies, i.e. providing supply side data from SD models and demand side data from econometric models, might be considered rather obvious for an analysis of global resource flows. Due to extensive international data compilation and harmonisation efforts, state of the art economic modelling approaches can nowadays feature rich data coverage (like GINFORS does). Therefore, dynamic mappings of economic developments should also incorporate these available structures (i.e., global economic developments should be simulated by a model like GINFORS). Compared to these harmonised economic datasets, the availability of reliable data might not suffice for an econometric approach to the task of dynamic supply projections. Hence, given econometric demand projections, additional methods have to be involved if one wants to integrate dynamic supply projections.

In our view this soft-link achieved proves the feasibility to drive SD-based supply side projections by economic demand projections which are not exposed to (at least not to many of) the criticisms originally brought forward against the WORLD3 model as developed by Meadows et al. Still, from an academic perspective it would be highly interesting to see how the economic projections in the soft-linked modelling framework would compare to WORLD3 economic module driven WORLD model projections and what this implies for post 2050 results from WORLD.

Policy mixing as a more systemic approach to policy making – concept and challenges

The concept of policy mixing can be considered a more systemic policy response to managing complex systems and to fostering transitions towards more sustainable resource use. Policy mixes in the sense of instrument mixes have been applied in environmental policy in various contexts. However, policy mixes seem mostly to have been designed in the sense of adding new policy instruments when necessary, without considering potential interactions and long-term consistency, which may contribute to trade-offs and conflicts of objectives between the different instruments stacked upon each other, thus reducing the overall effectiveness of the policy mix. In contrast to this so-called policy layering, the theoretical policy mix concepts aims to serve as a heuristic to orient policy design, assessment of the mix and preparation for implementing it. This heuristic builds on several sequential and iterative steps:

1. Making objectives and concrete targets of the mix explicit;
2. Identifying key drivers and boundaries of the system/problem the mix shall address;
3. Selecting relevant policy instruments, which based on (scientific or at least heuristically done) ex-ante assessment have the potential to contribute to achieving the mix' objectives;
4. Combining instruments to foster synergies and minimise trade-offs and negative side-effects;
5. Preparing the final policy mix for implementation, enforcement and monitoring.

In this context, the policy mix design process should maximise (i) consistency between policy objectives and the instruments, and (ii) coherence of the processes needed to implement the mix. Beyond instrument interactions, coherence is essential between different policy and administrative levels so that the policy mix and its implementation fit as much as possible to the wider institutional conditions.

Thus, a policy mix goes beyond combining loosely policy objectives and instruments in a long-term systemic view.

This requires a forward-looking roadmapping process, i.e., relating different policy instruments to each other in a time sequence that helps optimising synergetic effects and minimising unintended negative side-effects; as well as consideration of political processes in polycentric governance systems in order to be able to identify and secure long-term multi-actor support, to monitor processes and adapt the mix in feedback loops over time in a coherent manner. Thus, the concept of policy mixes will challenge political practices and experience as political realities, as well as the dynamics and path dependencies of legislative periods, run counter to a strategic and more long-term implementation procedure of policy (mixes).

Furthermore, the policy mix concept encourages – or even necessitates –considering and including scientific assessment results when developing policy mixes. This proves challenging for several reasons: (1) robustly assessing cumulative impacts of policy instruments in a time-dynamic sequential manner is very demanding both in terms of conceptual and computing power (simulation models) of those undertaking the scientific assessment. (2) Linked to that, scientific findings will always come with a degree of uncertainty, which good scientific practice demands being communicated transparently, while policy making typically calls for concrete proposals with (near) certainty. (3) Policy making informed by or based on science needs to follow issues of legitimacy – in particular policy objectives, but also the final choice and design of policy instruments to be implemented in order to achieve the objectives, must be the result of democratic processes and political negotiations. (4) Hence, in the final decision making by democratically elected institutions, decision-makers must weigh different sources of knowledge and different options against each other in the context of political and socio-economic feasibility. This necessitates skills and capacities among decision-makers for long-term views on potentially relevant effects, which are often based on uncertain (scientific) knowledge. A prevailing political economy of maximising chances to maintain power from one election term to the next rewards short-termism and a focus on immediate benefits – it discourages long-term thinking with more distant benefits.

Therefore, designing, implementing, and evaluating policy mixes poses a formidable challenge to scientific assessment and even more so to practical implementation in existing policy settings.

Policy mix concept and development applied in SimRess

In the SimRess project, the concept of policy mixing was applied to develop and assess policy mixes for systemic resource policy via two simulation models – without a focus on making the mixes fit for preparation for implementation. The research focus was on national resource policy, but through international value chains and trade flows also embedded into the European and international resource policy context. Hence, effects of international trends and policy actions on German resource policy and vice versa were considered in a systemic way.

Over the course of the SimRess project, we developed three different policy mixes approaches:

1. A systemic resource policy mix approach tackling key drivers and trends
2. A resource policy mix approach based on selected ProgRess II policy instruments
3. A systemic resource policy mix approach aimed at contributing to more ambitious, longer-term resource policy targets

They show a different level of detail because of stakeholder feedback in the ongoing national resource policy context and due to the requirements of the simulation model used for their ex-ante assessments. According to stakeholder feedback and the project's nature as a research project, we completed only the first three iterative steps (up to undertaking ex-ante assessments) for the two last of the above three policy mix approaches developed. The first policy mix was considered less relevant in the contemporary resource policy context of ProgRess II, hence this was not included in the ex-ante assessments. For all three policy mix approaches we then described

a) the objectives and targets set;
b) the underlying conceptual causal system model;
c) the selection of instruments for the policy mix;
d) the scientific ex-ante assessment of the policy mixes' potential effects.

While the underlying conceptual causal system model is similar for all policy mixes in relation to the problem situation and the need for systemic resource policy responses, the third of the above three mixes was designed to pursue the most ambitious policy objectives, which are not part of Germany's official resource policy. Furthermore, due to the specific focus of the second of the above three policy mixes – selecting instruments from the existing German Programme on Resource Efficiency (ProgRess II), the instrument selection differs across all three mixes:

1. The systemic resource policy mix approach tackling key drivers and trends combines three policy mix approaches itself, each with a specific focus: (i) fostering sustainable production through incentivising sustainable consumer choices and improving availability – and affordability – of sustainable products and services; (ii) promoting sustainable production by financially rewarding sustainable production and products as well as international standards for sustainable products; and (iii) focusing on absolute reduction via a cap & trade system for materials on household level;
2. The resource policy mix approach based on selected ProgRess II policy instruments encompasses instruments aimed at fostering resource efficiency at all stages of the value chain: (i) Securing a sustainable raw material supply through environment friendly use of biomass materials; (ii) Raising resource efficiency in production by continuing and expanding funding programs for material- and energy-efficient technologies and processes as well as by nation-wide expansion of resource efficiency consulting; (iii) Making consumption more resource-efficient by means of greater support for resource efficiency through standard setting and increased product diversity in the Blue Angel 'protects resources' category. In addition, the use of cross-cutting instruments was taken into consideration via funding of research on resource-efficient, integrated solutions for planning, design, construction and refurbishment as well as dismantling, where feasible, of obsolete structures and recovery of construction materials for recycling and reuse;
3. In contrast to the first two policy mixes, we chose a different approach to design the systemic resource policy mix approach aimed at contributing to more ambitious, longer-term resource policy targets. The diversity of sectoral changes enabling the model simulation to achieve the targets set for this policy mix allowed only for inferring rather aggregated pointers for policy intervention at the coarse level of system transformation through ambitious policy that (i) focuses on reducing use of primary inputs and fostering secondary material use; and (ii) has the courage to address lifestyle changes and structural changes by rewarding such change and penalising lacking will for change, while as much as possible mitigating negative effects for losers.

The ex-ante assessment of the policy mixes 2. and 3. was undertaken in the environmentally-extended MRIO model GINFORS. The ex-ante assessments focused on potential economic and environmental impacts of the individual instruments.

Lessons learnt from applying and testing the policy mix concept in SimRess

The SimRess project provided opportunities to test and reflect on the concept of policy mixing for use in resource policy. While we could apply the first three iterative steps in the heuristic policy mixing concept, we found the conceptual development of the policy mixes limited

1. by stakeholder and project management decisions not to pursue further the conceptual development and scientific assessment of the systemic resource policy mix tackling key drivers and trends.

From a scientific point of view, albeit still constituting an instrument mix, this policy mix approach was developed furthest through testing internal consistency in order to exclude inconsistent mixes, where the instruments combined would suggest trade-offs of conflict of objectives;
2. to a mix of instruments in the resource policy mix based on selected ProgRess II policy instruments. They were neither tested for consistency, nor combined in a time-dynamic sequential manner defining which instrument(s) will come first and which will come later in what order;
3. to a reverse engineering based intervention logic of sector changes in a systemic resource policy mix approach aimed at contributing to more ambitious, longer-term resource policy targets, which we could not develop further into explicit policy instrument proposals.

Hence, as one key challenge we encountered the need to integrate input from science and stakeholders into the development of the policy mix approaches. In the political economy we encountered, this resulted in re-orienting the available conceptual and modelling capacities in the SimRess project towards investigating one policy mix approach based consisting of a small selection of ProgRess II instruments, which due to the ProgRess II dialogues was believed to receive wider societal and stakeholder support; and another policy mix aimed at more ambitious, longer-term resource policy targets sill in need of a wider societal debate on necessities and feasibility.

Owing to the specific capacities of and requests to the SimRess project, we were able to assess only a small fraction of existing and potentially conceivable and promising policy instruments in SimRess. This maybe disappointing from the perspective of scientific inquiry, but it is essential to keep the necessary dialogue between scientific evidence and policy making open and to help make science become applied in reality. Furthermore, only through such boundary management at the science-policy interface can the democratic legitimacy of (resource) policy making be maintained and undue outsourcing of responsibility on science to provide the silver bullet without any need for political negotiation rejected.

In our view, the objectives of the research project as well as the project capacities and the above stakeholder feedback did not allow the policy mixes to be conceptualised as a coherent whole for (theoretical) implementation. Because neither a comprehensive instrument selection and re-design of the mix based on ex-ante assessments, nor a roadmapping towards (theoretical) implementation of the mix could be carried out, the SimRess policy mixes do not represent policy mixes in the comprehensive theoretical understanding.

Another key challenge was the scientific, model-based assessment of the policy mix approaches. The quantitative model-based assessment of the policy mixes was confined to

- assessing individual instruments without a view on their potential cumulative effects (synergies or trade-offs from interactions). This was not a matter of lacking parametrisation capacities nor of insufficient computing power, but it was in fact due to stakeholder feedback and project capacities limiting the conceptual development of this policy mix approach;
- assessing potential impacts of changes in the demand of resource-relevant sectors towards target achievement, without translating the causes of such changes to policy instruments. The diversity of sectoral changes enabling target achievement in the model did not allow us identifying concrete policy instruments that could trigger these changes within the remaining time and budget.

Hence, assessing cumulative effects of instrument combinations over time was constrained by the conceptualisations of the policy mixes. But we cannot say whether, and if so to what extent, assessing such conceptualisations could be beyond the capacities of modelling tools. While the development of a policy mix as part of a research project can deliver scientific ex-ante assessments relevant for redesigning a policy mix, this process is complicated by:

1. the inherent difficulty of assessing cumulative effectiveness of a mix in contrast to that of the individual instruments; this remains a methodological challenge requiring more research. Furthermore, the specific modelling logic of the GINFORS simulation model used might limit its ability to model some instruments or instrument designs that could lead to systemic changes – assessing this was beyond the research tasks in SimRess and would require further analyses;
2. the logical gap between a scientific ex-ante assessment of a policy mix' potential effects and its actual implementation in real-world contexts, which will inevitably change the nature or design and hence the impacts of the mix through the political processes. Any policy mixing effort will experience several adaptation rounds during its development, refinement, implementation, evaluation and refinement, which may change the mix fundamentally from what it was initially meant to be based on an(y) initial scientific ex-ante assessment.

Developing consistent and coherent resource policy mixes can contribute to a much more systemic and possibly also a more effective strategy for policy-making. Nonetheless, no scientific policy mix conceptualisation, nor any ex-ante assessment can navigate the political processes, which may impact both on the eventual policy mix design and on its implementation. Hence, the limits in conceptualising policy mixes for implementation in the research context seem also linked to issues of political realities – not only do the constant need for negotiations and often clashing short-term needs and long-term visions complicate policy mix conceptualisation in the decision-making context, but also may the associated skills be mismatched with skills and expertise hitherto needed in policy careers.

Therefore, albeit a promising concept to improve systems thinking and long-term views in resource policy, policy mixing is met with formidable challenges, which need to be better understood in order to increase the applicability of policy mixing for systemic resource policy. Further research from organisational theory and political economy may help shed light on circumstances under which policy-mixing would be possible and through which skills and actions its feasibility could be strengthened.

Conclusions

System analysis seems well adapted to support forward-looking and systemic resource policy. Long-term ex-ante assessments, as aided by SD modelling, enable to look beyond the typical time coverage of simulation models used for policy advice – this can help identifying time delays and feedbacks otherwise undetected, notwithstanding the challenges associated with long-term policy making.

Furthermore, system analysis features means to meaningfully engage stakeholders, through the joint language of CLDs, into understanding a system and in jointly creating solutions in the system in question. However, as the SimRess project experience shows, there are many pitfalls that challenge or thwart successful stakeholder participation as well as further use of stakeholder participation results in the simulation processes.

Discussing an integrated modelling framework prove challenging due to the two modelling systems used having different underlying paradigms. The exchange yielded a soft-link between the two models, but it also highlighted that the models differ for good reasons in many aspects and that more such inter-modeller exchange is needed.

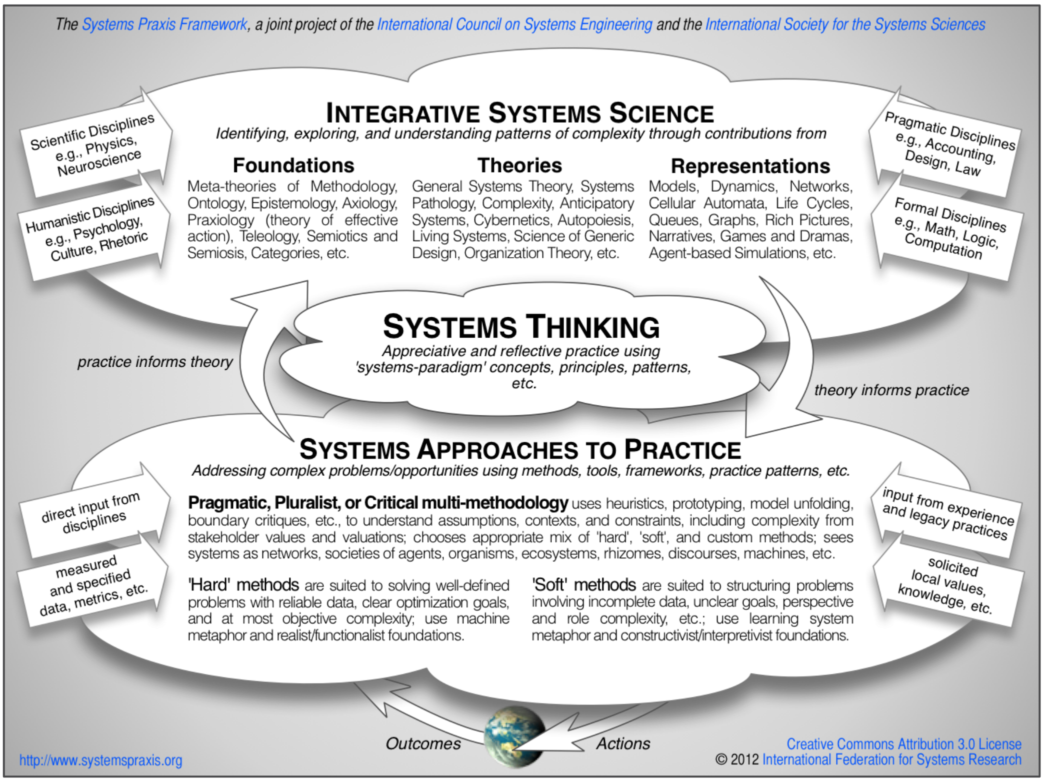
The concept of policy mixing appeared to fit well with system analysis as it could build on the CLDs elaborated for identifying generic interventions points. However, project capacities and stakeholder decisions steered the policy mix design process in a certain direction, which did not allow us undertaking a fully-fledged policy mix design process. While in our view, the policy mixing concept in general perfectly complements system analysis, it is very difficult to apply – in scientific ex-ante assessments, due to of challenges in parametrising and simulating cumulative effects of different instruments sequentially interlinked over time; and even more so in actual policy making as policy making practices, routines and environments are locked into shorter-term thinking and developing skills for long-term coalition building are discouraged.

1 Systems thinking approach used in the SimRess modelling work

There are many complex and interrelated issues with respect to resource use, scarcity, efficiency, and the resource-energy-climate nexus, all of which are within the focus area of resource policy. For a comprehensive understanding of such issues on resource policy, it is essential to analyse key dynamics and conditions in the complex natural resources system from many different aspects (i.e. political, environmental, social, technological, legal, institutional, economic), and from national to global levels. Only a systems thinking approach can provide a sufficient understanding of what new arrangements (political, social, technological, legal, institutional, economic etc.) are needed to interlink separate policies from a wide range of policy areas and sectors across value chains (from raw material extraction to end user consumption). It is also this understanding that can help decision makers to develop new and/or revise existing policy strategies and instruments.

Systems science aims to identify, explore and understand patterns of complexity through contributions from various disciplines, foundations, theories and representations (Figure 1). It is the use of systems thinking along with application of systems approaches, methodologies and tools (i.e. systems analysis and system dynamics) that make it possible to practice integrative systems science for studying and managing complex feedback systems in nature and society. In this respect, the systems thinking approach was adopted in the SimRess project.

Figure 1: Integrative systems science



Source: International Federation for Systems Research 2012

1.1 Conceptual modelling and systems analysis

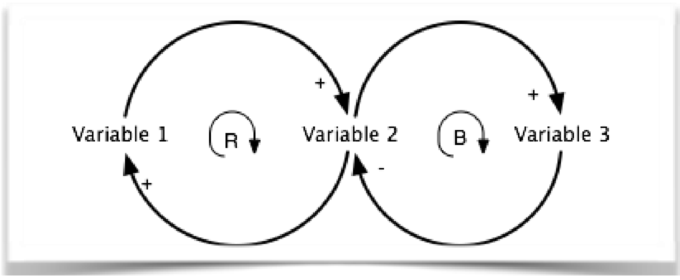
Systems analysis deals with detailed examination of systems and the interactions of elements within and between such systems by creating conceptual model structures with the help of causal loop diagrams and ideally over a group modelling process (Randers, 1980; Vennix et al., 1992; Vennix 1995; Vennix, 1996; Andersen & Richardson, 1997; Vennix, 1999; Maani & Cavana, 2000; Sterman, 2000;

Rouwette et al., 2002). More specifically, systems analysis helps to identify a problem and build a conceptual model of a system at the root of the problem by clarifying the cause and effect relationships and the feedbacks between different elements of the system.

Kim (1992) provides a good description of causal loop diagrams (CLDs) as "[they] provide a language for articulating our understanding of the dynamic, interconnected nature of our world. We can think of them as sentences, which are constructed by linking together key variables and indicating the causal relationships between them. By stringing together several loops, we can create a coherent story about a particular problem or issue" (Kim 1992, p. 1). They are used to show the linkages between different elements/variables in a complex system and help us to understand the cause-effect relationships and feedback loops within that system (Richardson 1986).

Figure 2 is a sample CLD. It demonstrates how the arrows that link each variable indicate places, where a cause and effect relationship exists. The plus or minus sign at the head of each arrow indicates the direction of causality between the variables when all other variables conceptually remain constant. More specifically, the variable at the tail of each arrow causes a change in the variable at the head of each arrow in the same direction (in the case of a plus sign), or in the opposite direction (in the case of a minus sign). The overall polarity of a feedback loop - that is, whether the loop itself is positive or negative - in a causal loop diagram, is indicated by a symbol in its centre. An "R" sign indicates a reinforcing loop (or equivalently known as positive feedback loop), and a "B" sign indicates a balancing loop (or negative feedback loop). In a reinforcing loop the action of the loop is to influence the parameter in the same direction as it is already moving, where as in a balancing loop it is to return the parameter to its initial value.

Figure 2: A sample Causal Loop Diagram (CLD)



Source: Authors

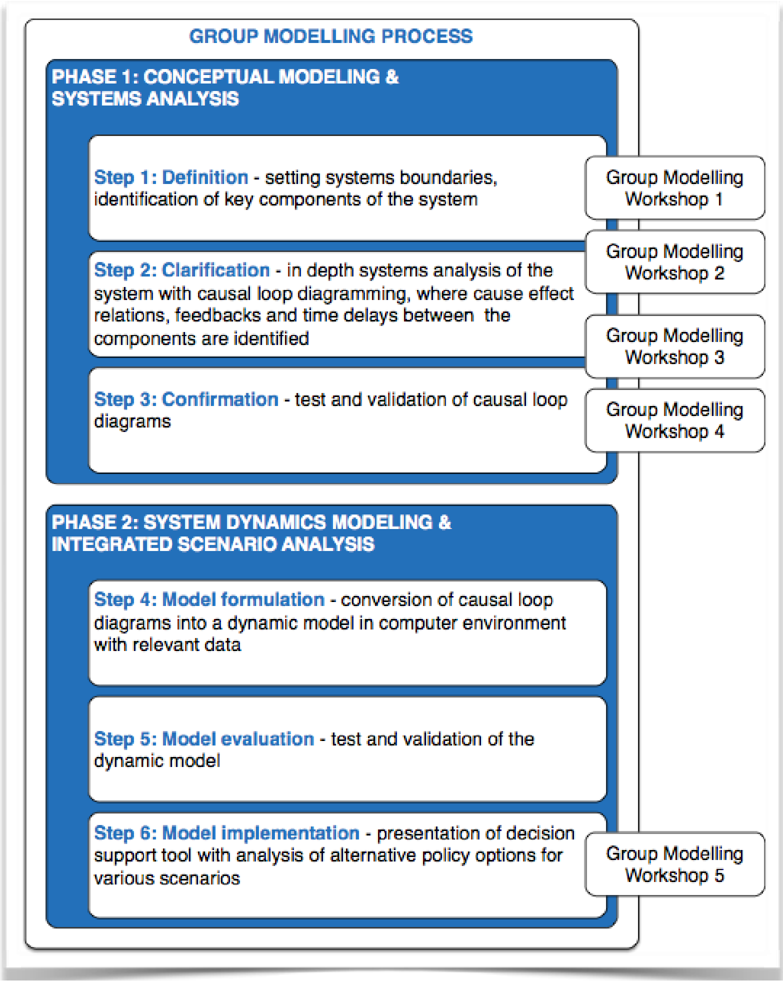
The use of CLDs as narrative visualisation tool is an effective way to identify, assess and communicate problems, their major root causes, associated symptoms, as well as the alternative solutions and the possible leverage points in dynamic complex systems. It is, therefore, essential to use CLDs for conceptual modelling and systems analysis of such complex and dynamic systems.

1.1.1 Causal loop diagrams and group modelling process in SimRess project

Group modelling process in the SimRess project:

A systems science based and stakeholder participatory group modelling process was intended to be used as a part of the SimRess modelling work (see Figure 3).

Figure 3: Two phases and six steps of the group modelling process3



Source: Authors

The stakeholder participatory group modelling process was meant to be a transparent and mutual learning process, where stakeholders would have the chance to exchange knowledge and experiences. Initially, a series of 4 group modelling workshops were planned in SimRess project with the main objectives of:

1. identifying key sector(s)/focus area(s) in Germany on which the global natural resource scarcity will have most impact;
2. developing an in depth systemic understanding of how these key sector(s)/focus area(s) look like today and how they could develop in the future;
3. developing conceptual sub-models for the selected key sector(s)/focus area(s);
4. identifying and elaborating on the existing and potential new resource efficiency policy measures and mixes for the selected key sector(s)/focus area(s).

The expected outcomes from the planned stakeholder participatory group modelling workshops would provide useful information to develop system dynamics sub-models representing the selected key sector(s)/focus area(s) that could run in parallel to the WORLD model, and also to contribute to

[3] See Koca and Sverdrup (2014b) for a full description of the methodology.

WORLD model development itself, as well as to identify potentially relevant intervention points for resource policy.

Stakeholder selection process in SimRess project

In a meeting with all SimRess project partners, we first identified the major industry sectors in Germany (basic metals, motor vehicle, machinery, chemicals, food and beverages, construction), as well as their main raw material suppliers and the final consumers of the products from these industries. We then discussed the structure of the supply chain from raw material to final consumption of end products, and the embedded logistics and trade activities. Moreover, we discussed the demand for energy and waste generation throughout the value chain for each of these industries and found almost all of them to be similar. With the main industries selected and the relatively generic supply chain in mind, the potential stakeholders were then categorized under 7 different groups (raw material suppliers, energy/electricity sector, logistics sector, production sector (6 industry sectors), waste sector, consumption sector and others) (see Table 1)

Table 1: Stakeholder categorisation

Category	Organisation	Description
Raw materials	Coal mining industry BP	Coal Oil
Electricity / Energy sector	EON Vattenfall	Energy Energy
Logistics	Schenker DB Maersk Harpag Lloyd Lufthansa	Land Land Water Water Air
Industries		
Basic metals	Umicore Algemine	Metal refinery Precious metal/base metals
Motor vehicle	Daimler	Car industry
Machinery	VDI VDMA	
Chemicals	VCI BASF Bayer	
Food and beverages	v. Löwenstein REWE Dr.Oetker	
Construction	Hochtief Verband der Zementindustrie (VdZI)	 Waste
Waste sector	Rethman	Waste & recycling
Civil society & consumers	Consumer association Churches	
Others Academia Media		

Category	Organisation	Description
NGOs	NABU	
	Friends of the Earth (BUND)	
Policy makers/agencies	UBA	
	BGR	Reserves
	DENA	Energy
	Ministry of Economics and Energy	Energy

Prior to the group modelling workshops, a two days long crash course on systems thinking and systems analysis was organized in order to develop a basic level of knowledge in systems thinking approach among the SimRess project partners, and to briefly introduce them to the working methodology of the workshops.

Despite comprehensive invitation management procedures, we experienced problems in securing a sufficient number of stakeholder representatives to participate to the group modelling workshops. After the first two workshops (See "A progress report of the two SimRess group modelling workshops" for outcomes), we decided to end the stakeholder participatory group modelling process mainly due to the very low response rate and number of participants (4 participants in the 2nd GMW of more than 70 invited!).

Among others, some of the plausible reasons for low response and participation rates could be explained by:

1. Lack of interest, time and personnel/capacities. Especially, representatives from industry and governmental organisations might have found it difficult to accept a long-term commitment to such group modelling process, where they had to participate several full-day long workshops considering their limited resources and time. The commitment of the stakeholders in participating to the entire group modelling process with all workshops is particularly important, because the combined knowledge and experiences of the stakeholders provide valuable input for the model development. Such commitment could not be secured among the stakeholders invited and those participating in the 1st workshop.
2. Language barriers. The participants might have felt uncomfortable with the fact that the group modelling workshops needed to be partially run in English (due to the international partners in the SimRess project)
3. Possible earlier dissatisfaction in previous workshops and/or fatigue of discussing larger question of resource efficiency in different sectors due to extensive participation of the targeted stakeholders in workshops of previous projects. The participants might have related the SimRess group modelling workshops to those previous workshops that they have been to and may not have seen added value in this new series or may not have found the previous workshops so useful.
4. Lack of information. Stakeholders might have not gotten sufficient information prior to the group modelling workshops, e.g. clearly defined objectives, questions to be answered etc., which are in a way against the nature of systems science based group modelling workshops, as it is the participants who are expected to agree upon to define a clear statement/key question/problem definition in order to state explicitly the purpose and objectives of the group modelling in an iterative learning process.
5. Constitutive challenges questioning the appropriateness of the planned group modelling process. It is self-evident that an analysis of complex interrelationships within the resource-energy-climate nexus requires a very comprehensive systemic modelling approach. And it is certainly true that, for any applied modelling approach, the conceptual definition of system boundaries already determines the subsequent findings from the model implementation phase in a normative manner. Due

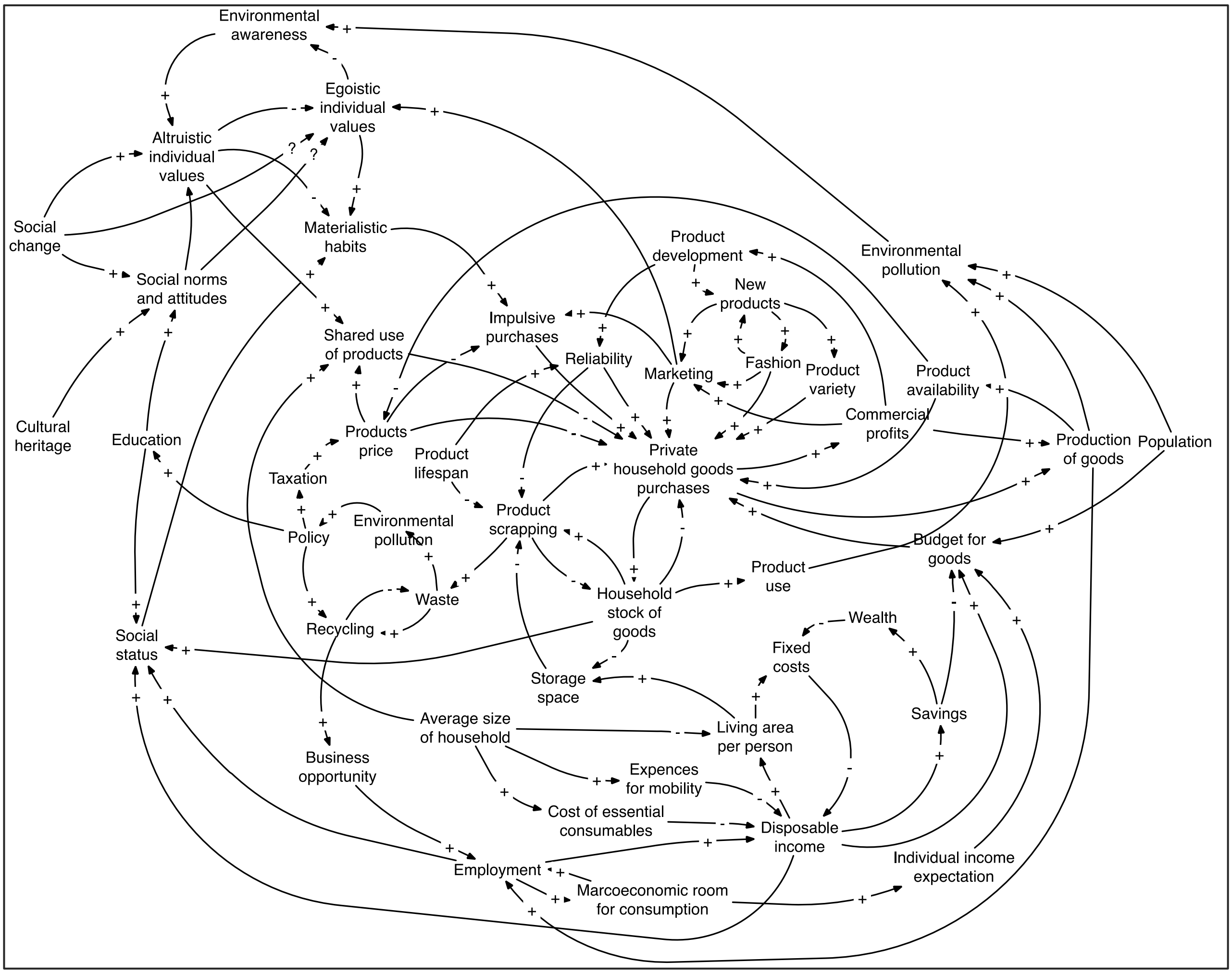
to the normative characteristics of this task, stakeholders might feel generally reluctant to commit themselves to concrete system boundaries. Thus, even if substantial information are provided to the stakeholders, they might nevertheless restrict their contributions to isolated annotations of specific sectoral experience but refuse to adopt a systemic view. At least, it seems plausible to assume that this kind of resistance is much more likely in cases of complex global problem settings (as they have been handled by the SimRess project) compared to rather straightforward problem settings on regional or even municipal levels.

Use of CLDs in internally organised group modelling workshops

Even though the stakeholder participatory group modelling process was terminated after the first two workshops, the SimRess project partners agreed upon continuing with internally organised system science based group modelling workshops.

An internal group modelling workshop was organised with the participation of SimRess project partners and representatives from UBA. The discussions focused on four thematic areas during the workshop: construction/infrastructure, private household consumption, employment and the environmental impacts of resource use in general. **Fehler! Ungültiger Eigenverweis auf Textmarke.**, as an example, shows the causal loop diagram built by the participants following their discussions around private household consumption and its environmental impacts.

Figure 4: Causal Loop Diagram with the theme of private household consumption



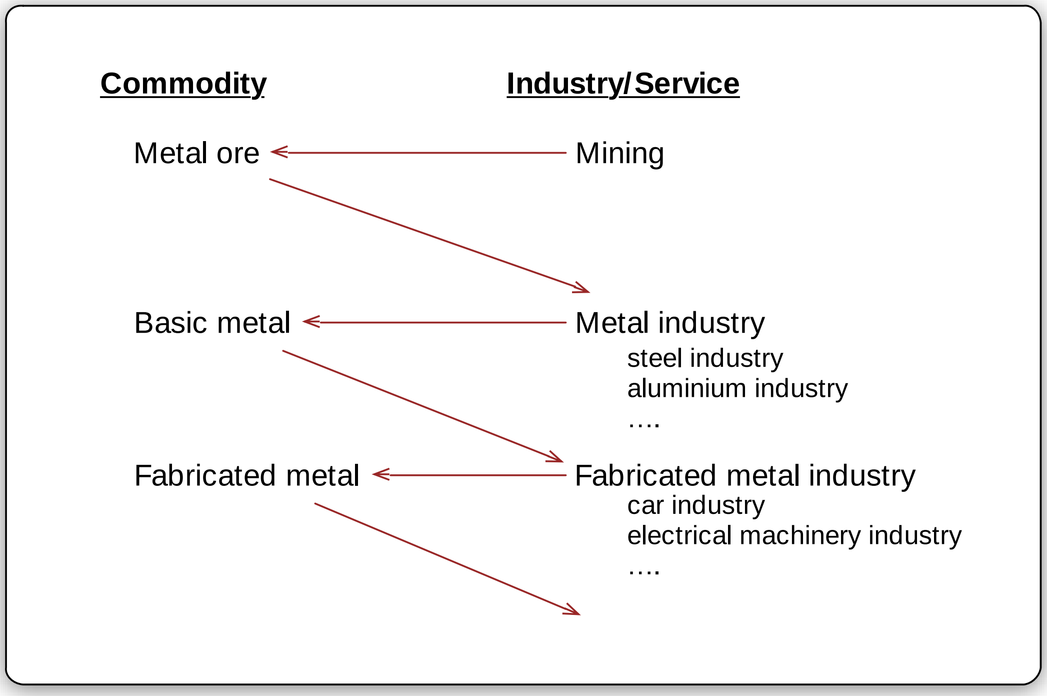
Source: Authors

The CLD methodology along with flow diagrams, was used internally among the SimRess project partners as a common communication tool during the internal group modelling workshops.

For example, in one of the workshops, metal ore was selected as an example commodity to see how other commodities and different industries/services are interlinked to each other throughout the whole value chain of the metal sector. Figure 5 and Figure 6 are two sample material flow diagrams showing these interlinkages between commodities and industries/services.

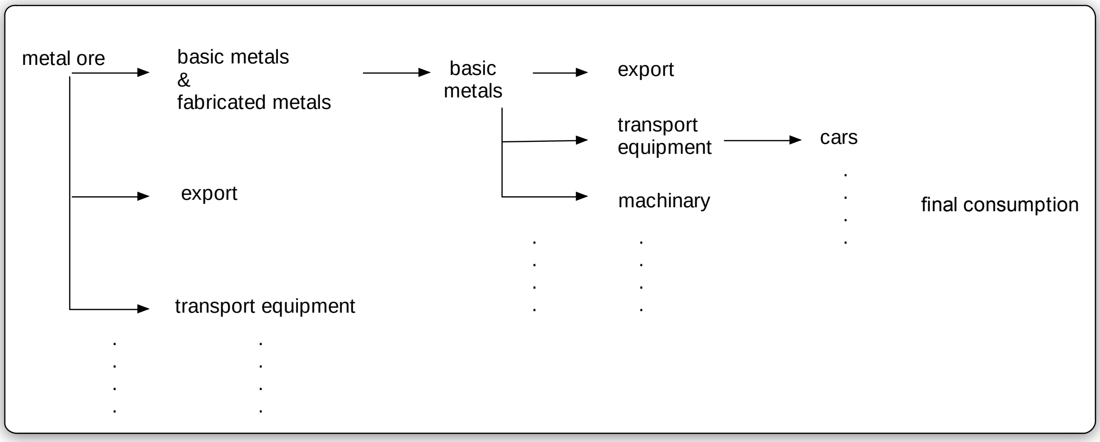
Once these interlinkages in the metal sector were identified, an attempt to draw a causal loop diagram was made as presented by Figure 7. The figure uses the information from Figure 5 and Figure 6 and looks deep into the cause-effect relations and feedbacks, which cannot be seen with the material flow diagrams. As Figure 7 suggests, high, low and ultra-low-grade metal ores constitute the metal ore reserves. The more the reserves the more can be the fabrication of metals. If the fabrication of metals increases there will be more fabricated metal available on the market and less metal ore in the reserves. Fabricated metals can be exported and/or used in manufacturing of transport equipment such as cars. The more it is exported or used in manufacturing cars the less will be available in the market. Throughout the value chain, waste is generated. Increased personal income (along with other socio-economic factors) increases the demand for cars, which in turn increases the manufacturing of transport equipment.

Figure 5: With mining industry, various metal ores are provided to different metal industries to be processed into basic metals. Different fabricated metal industries then turn these basic metals into fabricated metals.



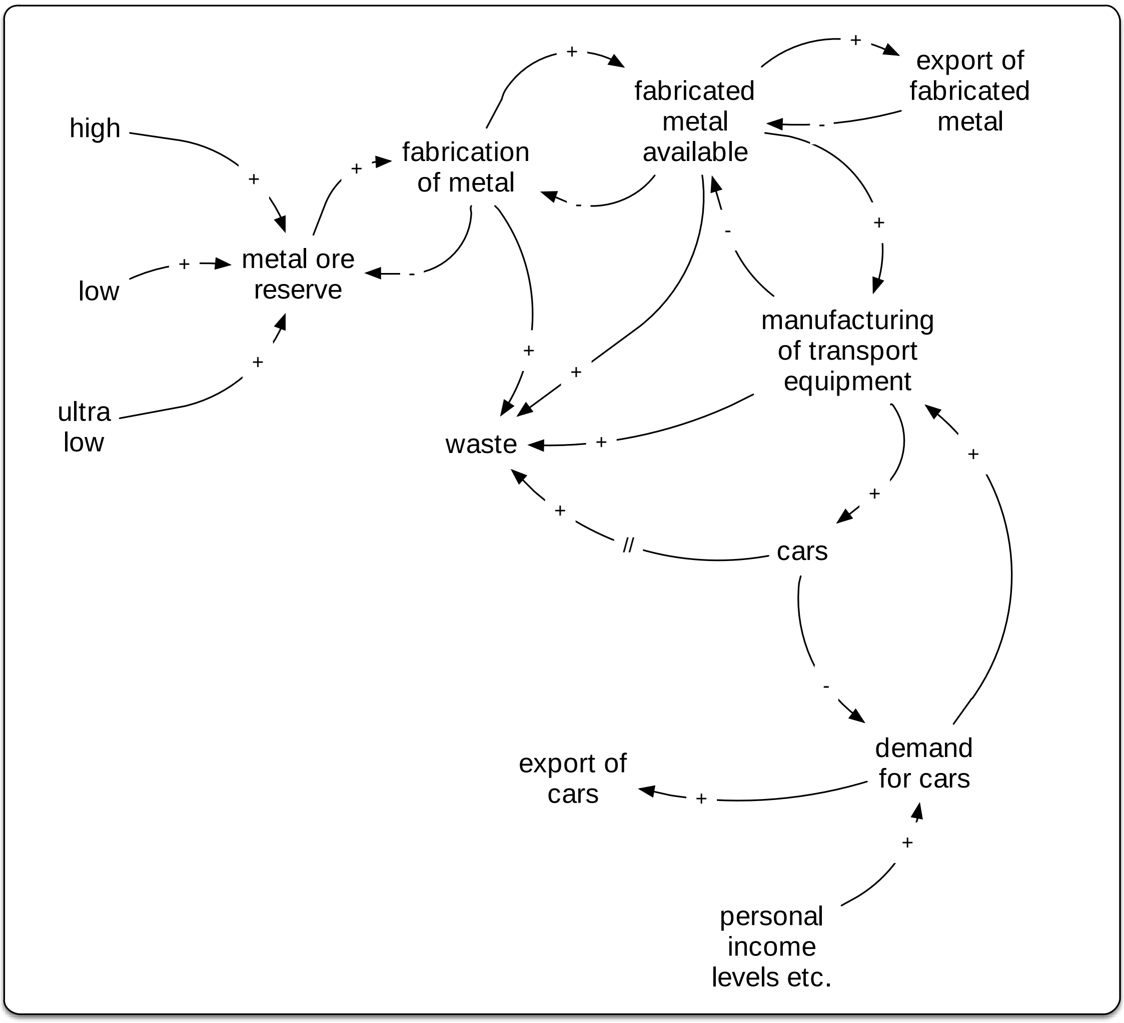
Source: Authors

Figure 6: Flow chart showing main services/industries using metal ore and basic metals



Source: Authors

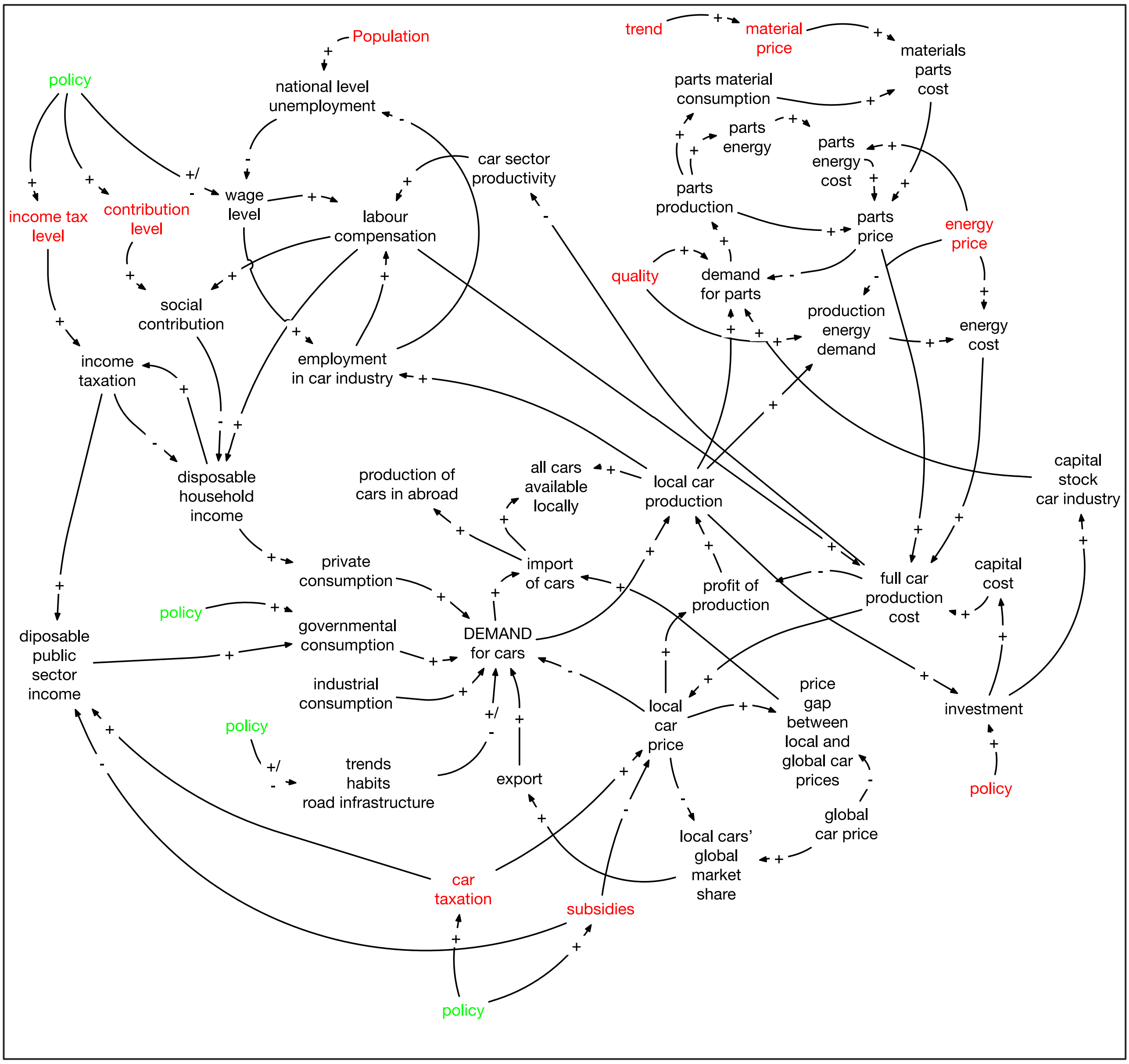
Figure 7: Causal loop diagram showing cause effect relations, feedbacks and time delays in the metal sector



Source: Authors

Similarly, during another internal group modelling workshop, we attempted to gain an insight of a part of the GINFORS model structure and the way it functions. Taking "cars" as a sample product group, a causal loop diagram was constructed in order to see the factors affecting the demand for cars and the production, as well as the cause-effect linkages between these factors (Figure 8). Developing such a causal loop diagram also made it clear where some of the leverage points (places to intervene a system) (see Meadows, 1999) lay in the model structure as shown in red together with the potential policy implementation points shown in green.

Figure 8: Causal loop diagram showing the demand for cars and the production, and the causal linkages between these factors



Source: Authors

1.1.2 Potentials and challenges of CLDs

Causal loop diagrams allow qualitative analyses of complex systems and help to identify leverage points where interventions appear most promising of leading to significant benefits (please see here section 2.4).

The use of CLDs as a common language in participatory group modelling workshops ensures efficient and effective communication for a common understanding of complex systems. By providing a holistic view, it enhances brainstorming, capturing new ideas, quality of strategic thinking, planning, clarifying decision-making cycles, which all in turn increase team productivity and thus the quality of the workshop outcomes.

The main limitation for widely use of causal loop diagramming in group modelling is that the process requires an expert facilitator with proper skills, education and training as there is no one simple generic guideline to facilitate the workshops. Each workshop can be formulated differently depending on many factors including the diversity and the culture of the stakeholders, focus areas etc. However, apart from moderating skills, the identification and selection of stakeholders which qualify themselves for systemic analyses has also been identified as a key challenge of group modelling processes. Finally, the process also asks for a strong commitment from the stakeholders' side, which means that the stakeholders need to assign the necessary time, effort and resources to engage the whole group modelling process.

1.2 System dynamics modelling and integrated scenario analysis

System dynamics (SD) modelling is a methodology used to understand the behaviour of complex dynamic systems over time. It deals with internal feedback loops and time delays that affect the behaviour of the entire system. With improved level of knowledge obtained by conceptual modelling and systems analysis (see Figure 1), a conceptual model structure presented by CLDs can be taken into one step further and transferred into a dynamic numerical model with relevant available data (Coyle 2000; Maani & Cavana, 2000). SD is based on the principle that the feedback relationships between the elements/variables of the system primarily determine the system behaviour. Even though the underlying basic structure of the system remains the same, the individual elements/variables change over time. Since, each of the system elements/variables is interlinked to the parts of the system through feedback loops, a change in one element/variable affects the overall system and in turn the element/variable itself.

It should be kept in mind that modelling work of all dynamic and complex systems starts with a problem statement/identification followed by a conceptualisation, regardless of the computational method used for model formulation. Following the model formulation with relevant data, the model is then validated by different means. In SD modelling some of the most important tests regarding the structure and the behaviour of the model includes, but are not limited to, dimensional consistency check, structure assessment test, extreme conditions test, sensitivity analysis and behaviour reproduction test, with special emphasis on the last two. A sensitivity analysis allows a better understanding of model behaviour and more insights in the modelled system. It helps to see how sensitive the model behaviour is to changing values of the model components. This allows identifying the components, which are most sensible in the model and have the biggest impact under certain scenarios. A sensitivity analysis also makes it possible to see whether the model behaviour is mostly sensitive to the magnitude of the components or mostly sensitive to the structure, as such the way the components are related to each other. By performing a reference mode of behaviour reproduction test it is possible to systematically compare the time series of a particular variable in the model with a time series perceived in the system.

As an end product, the SD model serves as a decision support tool and provides the user with a risk free learning environment (in contrast to learning by implementations) to generate simulations for alternative scenarios with different implementation goals and objectives. The simulation results from system dynamics models provide the necessary outputs for an integrated scenario analysis.

SD modelling in SimRess:

As planned stakeholder participatory group modelling workshops were cancelled during the SimRess project, the SD modelling work focused on the further development of the WORLD model, not the development of sub-models for selected key sector(s)/focus area(s) that could run in parallel to the WORLD model. The overall aim with the SD modelling work in the SimRess project was hence to further develop the WORLD Model and use it as a decision support tool in simulating potential resource scarcities and testing selected resource policy approaches.

The WORLD model is a system dynamics model that runs iteratively to reflect the complex interactions between population, economy, food production, ecology and resources over an extended time span and aggregated to a global level i.e. all the parameters are global totals or averages, rather than modelling any differentiations between geographies. The WORLD model consists of several (sub-) modules, four of which (population, economy, land/food, and ecology) are identical to the ones presented in the latest instance of the WORLD3 Model (Meadows et al. 2005), which is not much changed from the original version (Meadows et. al., 1972). The data used in World3 model is of two types including historical data of key levels such as population and arable land, and other data derived from the modelling group's own analysis and/or other academic work that support the trends and interrelationships in the model (see Meadows et. al., 1972 for full reference). Incorporating World3 model in its structure, and enhancing it with a more detailed resources module and an additional simple climate module considering the CO2 emissions due to use of non-renewable energy resources, the WORLD model provides more detailed simulation results on the global supply of various resources, including metals (i.e. BRONZE (Copper, Zinc, Lead, Silver, Gold and the dependent metals Antimony, Bismuth, Cobalt, Gallium, Germanium, Indium, Cadmium, Tellurium, Selenium), STEEL (Iron, Chromium, Manganese, Nickel, stainless steel), LIGHT METALS (Aluminium, Lithium), SPECIALTY METALS (Platinum group metals, Molybdenum, Rhenium, Niobium, Tantalum, Tin, Rare Earth Metals), materials (i.e. phosphorous, stone, sand, gravel) and energy sources (i.e. oil, coal, and gas), as well as on the energy consumption associated to extraction of these resources. The detailed resources module of the WORLD model is well underpinned by hard data (e.g. Known individual metals and mineral reserves) and has been verified on available historical data (e.g. extraction amounts, price) for the period 1900-2010, which shows the strength of the SD modelling approach and its ability to recreate the past observed patterns from established causalities parameterized on hard data.

A detailed WORLD model documentation will be provided in a separate report and results of the WORLD model stand-alone assessments have been published in the peer-reviewed literature (see e.g. Sverdrup and Ragnarsdottir 2011, Sverdrup, Koca and Ragnarsdottir 2014, Sverdrup, Ragnarsdottir, and Koca 2014).

Over the course of the SimRess project, as a consequence of the limited scope of the stakeholder participatory group modelling process, we have not been able to develop system dynamics sub-models for national level key sector(s)/area(s) that could potentially run parallel to the WORLD model. On the other hand, two participatory stakeholder and several internal GMW with the use of causal loop diagrams provided us with valuable input to elaborate on the parts of the system representation of the WORLD model, more specifically for the resources system. The group modelling process helped to improve understanding of system boundaries, interlinkages and causalities between different elements of the individual resources systems modelled.

One central feature making the SimRess project stand out from other similar research projects was the explicit task of discussing and exploring options for a modelling framework that could integrate system dynamics modelling approach and results with econometric modelling approaches and associated results. Originating from different schools of thoughts and further developed in rather separate communities, both modelling approaches have their specific simulation and explanatory power, as well as strengths and limitations. To reflect on these and to try to identify options for improving information flows between the modeller teams (and eventually, between the models, as much as possible) was one of the aims of the SimRess project. In order to reflect on the challenges we encountered during this endeavour, the following two sections:

1. provide annotations on dynamic modelling of the structures of complex system interdependencies from an applied econometric perspective; and
2. based on these reflections outline how the two modelling approaches complement each other for use in system analysis.

1.3 Dynamic modelling of the structures of complex system interdependencies – annotations from an applied econometrician's perspective

The SimRess project explored a rather unique research approach to advance dynamic system analysis within the environmental policy domain: In addition to the previously mentioned system dynamics WORLD model, the global Multi Regional Input Output (MRIO) simulation model GINFORS3 was applied for international socio-economic scenario projections until the year 2050 (see Distelkamp and Meyer 2017 for a self-contained documentation and further references). This unique methodological property of the SimRess project generated promising opportunities for reflections on distinct features of the modus operandi practiced by scholars of different modelling traditions:

As already mentioned, the WORLD model adopts the WORLD3 model in its structure, which has been heavily criticized in terms of the reliability of methodology (i.e. the researchers and methods came from technical backgrounds and worked on topics of social sciences (Imhof, 2000; 15) and the data (i.e. in lack of sufficient empirical data, the model's database was rather weak so that the parametrised causal relationships were essentially derived from expert guesses for global averages instead of historical measurement approaches on a regional scale (see, e.g., Cole and Curnow, 1973 for an early comprehensive evaluation of WORLD3)). On the other hand, there have been also studies showing how WORLD3 results were more accurate than generally perceived (e.g. Simmons 2011, Hall and Day 2009, Turner 2008, 2012and 2014) despite the fact that the WORLD3 model was never intended to predict specific values or timing and making detailed forecasts. The model was rather intended to evaluate the pattern of behavior of five key variables, namely population, industrial output, food, pollution and non-renewable resources.

The above criticisms regarding WORLD3, extensively reported for instance in Cole and Curnow 1973, are generally known by both research communities, i.e., system dynamics modelers as well as social scientists. However, in the aftermath of these disputes, both communities continued to follow their own tracks and the respective models usually evolved and remained within distinguished research communities.

Whereas it does not seem very interesting to retrace individual discourses, it seems quite remarkable that there has not been any previous attempt to incorporate the outcomes from a state of the art dynamic Multi Regional economic simulation model in WORLD3's applied mapping of global socio-economic interrelationships as was attempted in the SimRess project.

The dynamic economic simulation model GINFORS3 has been conceptually developed, empirically parametrised and numerically implemented within a C++ environment by the project partners from GWS (see, e.g., Meyer et al. 2013 for an early reference to this model version). Rooted within well-established economic theories and evaluated by thorough empirical falsification tests it features a high degree of socio-economic policy relevance.4 Due to the prominent role of regression-based econometric

[4] See, e.g., Scrieciu et al. (2013) for an exemplary list of socio-economic simulation needs in contemporary policy consulting „[…] there is a need for structural macroeconomic models that portray capital and trade flows across countries and

methods for the selection and specification of its behavioral equations it is sometimes called an "econometric" model. Whereas this label might be discussed controversially,[5] it does provide a sound description of the methodological background of the project partners from GWS. In order to illustrate the scientific advancements which might be achieved by soft-coupling WORLD with GINFORS3 as well as for a clarification of inherent modelling boundaries, the following annotations comment on the previously outlined system dynamics modelling approach from an econometric perspective.

Referring to Figure 3 we would first of all like to comment on the conceptual modelling & systems analysis phase. Admittedly, applied econometric analyses usually do not initiate from a visualization of underlying qualitative conceptual models. This does of course not imply that econometric analyses do not rest on well-defined conceptual models. They do so. However, compared to qualitative conceptual models they will usually rest on effectually reduced conceptual models in order to achieve a meaningful numerical model implementation.

This instance might be exemplified with references to Figure 4. Whereas economists would never deny that (i.a.) "Social norms and attitudes", "Egoistic individual values [or, in economic terms: preferences]" or "Altruistic individual values [preferences]" do indeed influence private households' consumption decisions, we can hardly imagine any possibilities to derive objective and valid metrics for these variables which would also allow to incorporate them in a numerical simulation algorithm.[6] Hence, the (non-disputed) qualitative causalities arising from and between "soft" variables (like social norms and individual preferences) would usually not be explicitly represented within the conceptual mapping of an econometric model.

Accordingly, we acknowledge that the supplemental efforts to start a modelling process with a qualitative CLD-based system analysis might certainly enable modelers, clients and stakeholders to generate additional qualitative insights into the problem under inspection which would not be uncovered by a traditional econometric approach. Insofar, compared to consecutive derivations of a numerical simulation model by continued refinements of an initial CLD as suggested by Figure 4, we do rather see qualitative CLDs to fulfill a broader and independent function: They define the boundaries of the system under analysis, identify all relevant drivers within the system and depict their underlying causalities. As such, most benefits can presumably be derived from qualitative CLDs in the model application phase: They provide a comprehensible visualisation of relevant nexus whose overall polarities might only be assessed by dynamic model simulations. For clients and stakeholders CLDs might thus serve as a menu to place their orders for insightful model applications.

Whereas the above comments were basically referring to phase 1 of the modelling process, they already gave a hint to the intrinsic challenges of numerical parametrisations and evaluations of simulation models (which represent the key working stages in phase 2 of the modelling process). Looking back on the "soft" variable issue discussed above, we would like to note that our previously expressed concerns about potentially misleading quantifications of unobservable variables should not be considered as some kind of abstract intellectual game. Neither should they be misinterpreted as isolated concerns discussed solely within the econometric society. In fact, we can also refer to Coyle (2000) in this regard who cites Forrester (1961, p. 63) as follows: "In the proper formulation of a system dynamics model the model variables should correspond to those in the system being represented. … Sufficiently

across time, and accommodate for the existence of resource unemployment and their suboptimal use that respond endogenously to climate mitigation policies." (Scrieciu et al. 2013; S. 262).

[5] For being more precise one might rather refer to the INFORUM approach outlined by Almon (1991), as Almon introduces a methodological classification scheme which does explicitly distinguish INFORUM-type models from classical econometric models.

[6] As a matter of principle, these variables cannot be measured on a cardinal scale. One might of course define some kind of ordinal metric and apply this in historical analyses of observed household behavior, but it seems (at least) highly questionable to us whether such parametrisations should be applied in ex ante assessments of individual policy options.

close correspondence of model and real-system variables is obtained [by carefully ensuring that] the decision functions represent the concepts, social pressures and sources of information that control the actual decisions." – A cautious interpretation of Forrester's recommendation should at least warn model builders against less reflected attempts to quantify causal influences which are not observable within the real-system: Whereas many "soft" variables do certainly influence societal processes, a fair approach to the task of quantifying a dynamic numerical simulation model should always ask whether their quantification might really be of any value for the later simulation outcomes. See also Coyle's own comments in this regard: "[…] the determination always to quantify […] may lead to models that are […] valueless, or even, when practical decisions are involved, damaging." (Coyle, 2000; 233).[7]

At this point, we have to assert that the dynamic properties of the parametrised simulation model cannot be assessed from an isolated view on the incorporated causalities. Hence, due to an intrinsic lack of necessary information, unambiguous conclusions about key quantitative features of the model cannot be derived from sole inspections of qualitative CLDs.

Letting y denote a single variable represented within a CLD and $x_j, j \in \{1,2,\ldots,k\}$ denote all variables with direct influence on y, the respective information content of a CLD can be mathematically written down as

$$y = F(x_1, x_2, \ldots, x_k).$$

However, in order to enable a computer to simulate this causal relationship, any model builder has to decide about the dynamic properties of the assumed functional relationship. Falling back to the mathematical notion of a total differential

$$dy = \frac{\partial F}{\partial x_1} dx_1 + \frac{\partial F}{\partial x_2} dx_2 + \ldots + \frac{\partial F}{\partial x_k} dx_k,$$

this implies that the dynamic properties of the parametrised model are determined by a modeler's choices with regards to the partial derivatives $\frac{\partial F}{\partial x_j}$.

In social sciences this constitutes a key challenge: In contrast to mechanical engineering studies, these parameters do not reproduce any natural laws which might simply be measured in isolated experimental setups. Given reliable and valid historical observations, econometric methods enable researchers to estimate these parameters empirically.

But what happens in cases of unobservable "soft" variables? Referring back to the top left area of Figure 4 we might for instance remind our readers that "social norms and attitudes" appear conceptually to depend on "social change", "cultural heritage" and "education". Doubting that valid real world figures might enable a reliable measurement of any of these concepts, an econometrician would presumably refrain from any attempts to parametrise these relationships. Technically, it is of course always possible to imply some kind of (non-evaluable) "expert guess" in place of empirically estimated parameters. However, as long as no supplemental information was amended to a CLD, these parametrisations are then solely subject to the group of modelers' discretion which is based on accumulated

[7] To illustrate this point a little bit further we can easily exemplify additional variables whose analysis should, according to our understanding, remain restricted on a qualitative level. See, e.g., concepts like affluent lifestyle, efficient democracy, political stability, public awareness of environmental damages, social infrastructures or social trust in this regard. As a matter of course it might be highly relevant to reflect these concepts and their long-run interdependencies (among other variables) in systemic approaches to policy making. And there are no fundamental technical restrictions which would preclude any attempts in this regard. But, even if policy makers insisted in a quantification of these effects, we would nevertheless, doubt that these efforts would provide any serious simulation insights.

knowledge and expertise of the stakeholders who are participating to the group modelling process. And it is hard to deny that some kind of arbitrariness separates then the shared perceptions of a modelling group with regards to their commonly established qualitative CLD from the resulting dynamic properties of the finally parametrised simulation model.

Until now, we discussed solely the issue whether conceptual structures given by a qualitative CLD might be directly transferred into a dynamic numerical algorithm with concerns about non-quantifiable concepts. But one should also be aware that, even if all CLD structures were unambiguously quantifiable, empirical model evaluation tests might disclose serious modification needs of the initial conceptual model. Essentially, it seems implausible that even the most carefully selected expert groups might be able to identify all relevant concepts, causalities and information flows which actually do control real life decisions. And even if an initial CLD was parametrised in a way that resulting numerical outcomes seemed to emerge to a plausible ensemble, this does not reduce the need to sufficiently and carefully validate the quantified model.

The econometrician's answer to this question highlights the relevance of Popper's positive concept of science (Popper 1994): Accepting that every quantifiable and implementable simplification of reality (i.e., every simulation model) has to be inevitably wrong, the task is not to identify and validate a "true" model parametrisation. One should rather apply impartial tests in order to decide, whether these simplifications do still represent valuable tools for policy analysis. As a sub-discipline of economic science, econometrics has been in place at least since the mid of the 20th century when seminal contributions from the so-called "Cowles Commission" established thorough parametrisation routines for the numerical implementation of large scaled structural (i.e., causal) macroeconomic simulation models (see Christ, 1994 for further references in this regard). As these models were already dynamic they also documented the empirical relevance of lag structures (i.e., delays in systems dynamics wording).8 But the main achievements of these constitutional works are certainly given by their formal cognition of inevitably inherent uncertainties of empirical quantification attempts and the development of suitable measures to account for these uncertainties (based on concepts from probabilistic science). In this regard econometricians developed various statistical testing procedures since the mid of the last century which can nowadays be applied straightforwardly in respective falsification exercises. Own experience confirms that on the model formulation and evaluation stage applications of these tests do more or less continuously force model builders to scrutinize their initial conceptual framework. Apparently, such cognitive insights represent a primary benefit of applied quantification procedures. However, these benefits can only be attained if thorough applications of econometric methods provide an opportunity for disclosing initial conceptual shortcomings which can then be overcome by subsequent revisions of the prior conceptual mapping.

All our previous comments suggest that the decision to quantify conceptual models should always be accompanied by additional meaningful documentations which provide sufficient information about the implied dynamic features of the parametrised model. Traditional econometric practice would suggest the publication of each model equation together with confidence intervals for all involved parameters. Yet, one has to admit that this line of action can de facto only be followed as long as the dimension of the model under inspection does not exceed certain thresholds. Referring to GINFORS3, these thresholds are certainly exceeded as the actual model version does account more than 3 million time series. Not all of these time series are mapped by individual reaction functions. Nevertheless, the informational value of an attempt to document each reaction function of the model can well be questioned. Insofar it is an inevitable feature of complex large scaled models that one can effectively not infer their implied systemic properties by looking at individual equations.

[8] Actually, many early model implementations were primarily intended as empirical analyses of business cycle dynamics.

Whereas this feature might be criticised we would like to recall that these large scaled models exist in order to provide consistent mappings of complex and interrelated system responses to discrete variations of selected variables over time. As exemplarily illustrated by Figure 4, it is simply impossible to derive overall polarities of complex feedback loops from the visual inspection of a given CLD. Such assessments can only be performed by means of quantitative model simulations. At the same time, such assessments do (at least implicitly) expose important modelling assumptions. As a matter of fact, we do not learn much about a numerical simulation model by simply looking at it (or the outcomes of an isolated model run). But its dynamical properties can be straightforwardly observed (and qualitatively assessed) by a comparison of model results under controlled variations of selected variables. Thus, as a key recommendation in order to overcome any potential "black box" skepticisms we would generally recommend assessing the implied assumptions of large scaled models by a comparison of findings from several controlled simulation experiments.9

Beyond this reflection of model specific strengths and limitations, the mutual learning process between system dynamics modelers and econometric modelers over the course of the SimRess projects enabled us to draw some lessons learnt on improving information flows between the two modelling approaches as well as to reflect on how the two models could best complement each other towards more robust system analysis. These lessons learnt are highlighted in the following section.

1.4 How do two modelling approaches complement each other in terms of system analysis?

The previous subsection highlighted methodological issues faced in the soft-linking of the two models during the SimRess project. This subsection expands these reflections by discussing the enlarged system boundaries of soft-linked simulation studies incorporating WORLD and GINFORS3.

It is rather obvious that macroeconomists are highly qualified for the analysis of complex dynamic systems as they are regularly trained to study the interplay between millions of corporations and private households together with mutual actions of the government sector and foreign developments on national levels. Doing so, they are well aware that the involved processes of income generation, income distribution and resultant expenditure decisions have to be analysed as interdependent circular flows which feature reinforcing as well as balancing feedbacks.

Thus, on a generic level, one might interpret the previous presentation of systems analysis as an abstract introduction to an analytical practice which should already be well understood by experienced macroeconomists. Perhaps these analytical similarities tended to be obscured by the fact that the discipline of system dynamics as well as economists developed individual taxonomies for analogical concepts. The system dynamics notion of reinforcing or balancing loops for instance might be much better understood by economists as individual occurrences of rebound effects (Sorrell and Dimitropoulos, 2008; Sorrell et al., 2009).

Like other economic-environmental simulation models developed and maintained by GWS (see, e.g., Lehr et al. 2012 for references to the national dynamic simulation model PANTA RHEI), GINFORS3 provides a detailed mapping of the developments of economic structures over time. And this on a global scale: The mutual interdependencies between 38 national economies as well as a rest of world region can be projected until the year 2050. As outlined before, these projections feature a high degree of reliability as the model implementation process is guided by established economic theories whose

[9] The documentation of the GINFORS3 results for the reverse engineering exercises (Distelkamp and Meyer 2017) might serve as an example in this regard. See furthermore also Köhler et al. (2016) for a most recent policy advice in favour of co-ordinated modelling exercises.

explanatory powers were empirically tested by applications of (panel-)econometric estimation methods by the model authors.

Regional production activities, induced labor demand as well as intermediate supply chains are globally mapped on base of the World Input Output Database (WIOD).10 This mapping rests of dynamic projections of so-called input coefficients, i.e., percentage ratios of annual monetary expenses for intermediate inputs goods in relation to the monetary value of total annual output of a given industry. All input coefficients are generally mapped as price dependent variables which follow long run technology trends. Compared to globally averaged economic projections as applied by Meadows et al. (1972), GINFORS3 thus features an extensive coverage of up to date economic datasets.11 Its historical database spans over the 1995 to 2009 period, distinguishes 35 individual industries, 59 product and service groups and four institutional transactors (corporations, private households, government and transactions abroad) within each modeled world region. As such, already the historical analysis of the model database generated constructive insights within the joint modelling process.12

Within these data structures the relations between energy use, resource use and economic development are reported in deep sector detail, which allows for a realistic analysis of policy impacts.13 As the dynamic modelling accounts also for income effects resulting from (i.a.) diversified investment expenditures, induced efficiency improvements or sustained shifts in consumption patterns, each simulation run also accounts for potential macroeconomic rebound effects in a variety of ways.

In SimRess, GINFORS3 was applied to generate global outlooks on overall economic performance until 2050. Aggregated demand figures (which otherwise had to be derived within the traditional economic module of World 3 model) were then fed from GINFORS3 into WORLD in order to derive detailed projections of global extraction activities. This exchange of information enabled the project team to produce endogenous projections of global metal ore prices: Usually, these price trajectories represent one of the few exogenous model variables in GINFORS3. These price dynamics are however endogenously derived from supply side dynamics in WORLD. Thus, in an iterative soft-link procedure, coupled simulation exercises proved the feasibility of integrated world market price projections featuring a balanced consideration of global supply and demand dynamics. Additionally, GINFORS3 proved its policy relevance on the environmental domain within various self-contained simulation experiments within the SimRess project. The Multiregional Input-Output (MRIO) structures of the model facilitate (i.a.) a calculation of material and CO2 footprints. Prospects and frontiers of currently discussed resource policy measures could thus be quantified and discussed within the resource-climate policy nexus by isolated GINFORS3 applications.

This combination of methodologies, i.e. providing supply side data from SD models and demand side data from econometric models, might be considered rather obvious for an analysis of global resource flows. Due to extensive international data compilation and harmonisation efforts, state of the art economic modelling approaches can nowadays feature rich data coverage (like GINFORS does). Therefore, dynamic mappings of economic developments should also incorporate these available structures (i.e., global economic developments should be simulated by a model like GINFORS). Compared to these har-

[10] See Dietzenbacher et al. (2013) or Timmer et al. (2015) for further details and applications of the WIOD database.

[11] The WIOD database has been initially released in 2013.

[12] Actually, the commodity flows illustrated within Figure 1.1.1_3 represent the outcomes of a straightforward statistical analysis of the inter-industry flows represented within the WIOD database.

[13] Referring to the claimed realism of $GINFORS_3$ simulations we might also refer to Ahlert et al. (forthcoming). Based on numerical evidence from identical integrated assessment exercises involving $GINFORS_3$ as well as, in a benchmark case, a neoclassical CGE-model they conclude that the neoclassical mappings seem seriously biased as they are derived within (non-contested) perfect economic world assumptions. Compared to this, $GINFORS_3$ tries to identify the deviations from hypothetical perfect assumptions by its applied econometric parameterization routines.

monised economic datasets, the availability of reliable data might not suffice for an econometric approach to the task of dynamic supply projections. Hence, given econometric demand projections, additional methods have to be involved if one wants to integrate dynamic supply projections.

In our view this soft-link achieved proves the feasibility to drive SD-based supply side projections by economic demand projections which are not exposed to (at least not to many of) the criticisms originally brought forward against the World 3 model as developed by Meadows et al. Still, from an academic perspective it would be highly interesting to see how the economic projections in the soft-linked modelling framework would compare to WORLD3 economic module driven WORLD model projections and what this implies for post 2050 results from WORLD.

2 Policy mixing as a concept for systemic resource

2.1 The need for more systemic responses in resource policy

Around the globe, the magnitude, scale and complexity of environmental problems are on the rise – as global climate change, increasing resource depletion and degradation of bio-physical systems indicate (Balint et al. 2011). In the wake of population growth and urbanisation (set to raise the share of urban dwellers of total global population to around two thirds, or ~6.5 billion by 2050) there will be between 2 and 3 billion more middle-class consumers, predominantly in Asia and to a much lesser extent in Africa (WBGU 2016; EEA 2016). Linked to the diffusion of westernized consumption patterns, this rise in middle-class consumers and consumption aspiration will have tremendous implications on the use of resources (Hirschnitz-Garbers et al. 2015; Wiedmann et al. 2015) and the state of the world's ecosystems: Schandl et al. expect resource consumption to reach approximately 180 billion tons of minerals, ores, fossil energy carriers and biomass by 2050 (Schandl et al. 2016), more than doubling from the roughly 80 billion tons reported for 2015 (UNEP 2016). The use of resources, and in particular the production of bulk materials (e.g. steel, aluminium, cement and polymers), and their transformation into consumption goods, infrastructure, and housing is responsible for a significant share of human energy demand and greenhouse gas (GHG) emissions (International Energy Agency 2008; Brown et al. 2012; Duarte, Mainar, and Sánchez-Chóliz 2013).

Furthermore, resource use across the entire value chain and the associated environmental impacts contribute to (further) transgressing existing planetary boundaries: for biodiversity loss and biosphere integrity; land system change; biogeochemical flows; and climate change scientific findings indicate that control variables are in or even beyond the zone of uncertainty (W. Steffen et al. 2015; Rockström et al. 2009). If these system states remain in or beyond the zones of uncertainty, there is high risk that the systems might tip (e.g. thawing permafrost in subarctic zones; changes in the Indian monsoon system; declines in boreal and tropical forests), which in turn might lead to complex cascades of adverse effects on human development; this even bears the danger to shift the system equilibrium of the Holocene towards new states, which are unknown in their implications on humanity (Lenton et al. 2008; Will Steffen et al. 2011). In this context, the planet's carrying capacities will be in significantly overshoot, with human activities expected to require two planet Earths around 2030 (Moore et al. 2012).

These environmental problems not only put strain on ecosystems, but also on socio-technical systems that are dependent on or coupled with these (Smith, Stirling, and Berkhout 2005).

Against this background, there is a growing need for more systemic responses (see e.g. Ekvall et al. 2016). This necessitates thinking about and fostering transitions towards more sustainable socio-technical systems and behaviour in environmentally relevant key domains such as mobility, food, and energy provision and use (Geels et al. 2015). Can policy support enable and foster transitions? How could more systemic policy approaches be designed?

2.2 The concept of policy mixing for resource policy

Policy mixing appears as a promising concept to support transitions that require systemic change. The many purposes that resource consumption serves (for instance fulfilling basic needs, providing pleasure, showing status and prestige; (Røpke 2009; Shove and Warde 2002; Gronow and Warde 2001)) and the multitude of involved actors in resource use make resource policy a clandestine candidate for thinking about a more systemic approach to policy making. Such an approach would need to allow policy makers to account for the most important aspects and causal relations between relevant drivers and factors when designing policies. Furthermore, such an approach calls for a very broad systems perspective in order to capture as much as possible the system's complexities (Ekvall et al. 2016). The concept of policy mixing may be an answer to this call.

Focusing on policy instrument mixes has emerged as a more nuanced model for analysing public policy in political sciences in the 1990ies. For instance, Gunningham and colleagues (Gunningham, Grabosky, and Sinclair 1998; Gunningham, Neil; Young, Mike D. 1997) investigated optimal policy intervention in the context of combining selective regulation with market-based approaches to design sophisticated instrument mixes. Further research found the design and implementation of policy mixes to be very much context dependent so that information deficiencies, existing actor constellations and strategic considerations, which enter decision-making processes in real-world situations and increase the risk of mismatch between policy instruments and outcomes, complicate policy mixing (Howlett 2004; Minogue 2002).

Policy mixes in the sense of instrument mixes have been applied in environmental policy in various contexts (e.g. OECD 2007), inter alia: for a more sustainable management of Icelandic fisheries by setting total allowable catch rates, introducing individual tradable quotas and adding a fisheries resource rent tax (Arnason 2008); to reduce primary aggregate use through an instrument mix consisting of an aggregates levy and a landfill tax for construction and demolition waste, with partial recycling of tax revenues to support research and development for the use of secondary aggregates materials (Söderholm 2011); for reducing plastic waste in the environment in Ireland through introducing a tax on plastic bags accompanied by voluntary initiatives and awareness-raising campaigns (Ecorys, Cambridge Econometrics, and COWI 2011); for reducing fertiliser use in Denmark through national action plans comprising fertiliser taxation, monitoring and enforcement mechanisms and farmer extension services (Lindhjem et al. 2009).

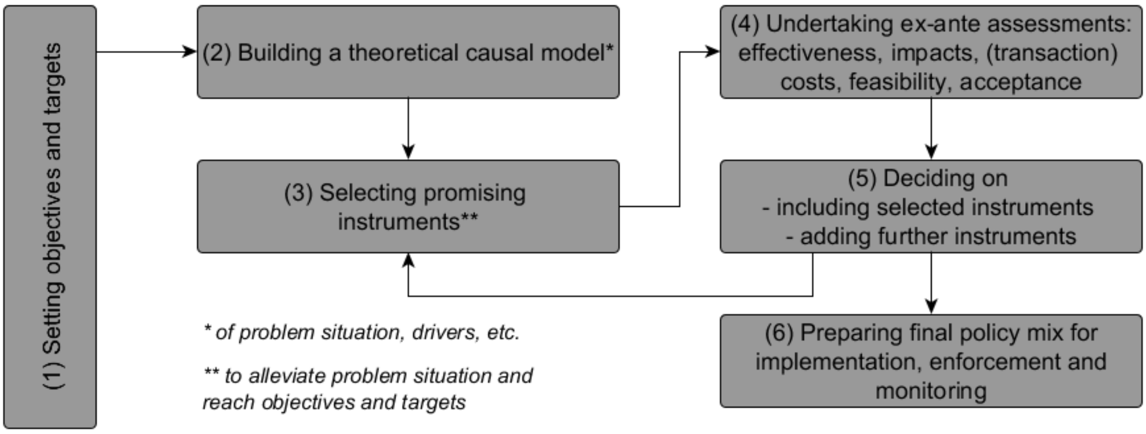
However, policy mixes seem mostly to have been designed in the sense of adding new policy instruments when necessary, without considering potential interactions and long-term consistency (Karoline S. Rogge and Reichardt 2016). This process has been called policy-layering and it may contribute to trade-offs and conflicts of objectives between the different instruments stacked upon each other, thus reducing the overall effectiveness of the policy mix (del Rio and Howlett 2013).

Policy mixing serves as a heuristic concept and orientation to both policy preparation in designing policy mixes and to research in (co-designing and) assessing them. This heuristic builds on several sequential and iterative steps which (see Figure 9):

1. Demand making objectives and concrete targets explicit that shall be achieved in relation to the problem situation;
2. Require understanding and structuring a given problem situation by identifying key drivers and defining system boundaries;
3. Ask for selecting relevant policy instruments (from an instrument inventory as comprehensive as possible), while this selection
4. Should be based on (scientific or at least heuristically done) ex-ante assessments of the mix' potential to tackle the key drivers and contribute to achieving the objectives and targets set;
5. Encourage thinking about combining instruments in a way that foster synergies, minimise trade-offs and reduce unintended negative side-effects to decide on the final policy mix design;

6. Assign responsibility to policy makers to prepare the final policy mix for implementation, enforcement and monitoring, urging them to consider political processes that are supportive to or impeding the design and implementation of the policy mix, both on horizontal (e.g. across policy fields) and vertical level (e.g. along hierarchies of competences) in order to support and maintain long-term, yet adaptive implementation of the policy mix (e.g. revision of instrument combinations).

Figure 9: Heuristic concept for policy mix development



Source: Ekvall et al. 2016; adapted from Givoni et al. 2013

For the iterative steps 3, 4, 5 and 6, the policy mix design process should aim to maximise both (i) consistency between policy objectives and the instruments sequentially linked in a policy mix, and (ii) coherence of the processes needed to implement the mix(es) (Karoline S. Rogge and Reichardt 2016). Consistency can be fostered by combining primary instruments, which mainly serve to achieve the/a set objective and should be as little controversial as possible, with supportive instruments, which aim to minimise or mitigate unintended negative side-effects of primary measures and, hence, to increase their acceptability and feasibility (Givoni et al. 2013; K.S. Rogge and Reichardt 2013). Beyond instrument interactions, coherence is essential between different policy and administrative levels so that the policy mix and its implementation fit as much as possible to the wider institutional conditions, such as various policy fields and governments active in these fields (so-called vertical mixing) (Howlett 2004; Howlett and Rayner 2007; Karoline S. Rogge and Reichardt 2016).

2.3 Promises and challenges of policy mixing

A policy mix goes beyond combining loosely or rather unconnected policy objectives and instruments. It links long-term qualitative and short- to mid-term quantitative objectives and targets to an instrument set in a time-dynamic sequential process – thus, it aims at enhancing the performance of the different instruments and exploiting synergies as much as possible to achieve the objectives and targets along the way.

However, in order for a policy mix to successfully respond to and be adapted to the specific context, it is important to consider: (i) The full range of policy instruments available and make use of different instrument mechanisms as appropriate (incentives, command and control, information and persuasion, infrastructure, enabling); (ii) The costs of policies for different actors (implementation costs for authorities, transaction costs and compliance costs for addressees); (iii) Potentially negative unintended side effects of the policy mix on target groups (e.g. issues of competitiveness for industry or regressive effects on lower-income households); (iv) Options to combine instruments to mitigate such side effects; (v) Political processes during design and implementation (Howlett and Rayner 2007; del Rio and Howlett 2013).

Therefore, compiling a policy mix and preparing it for implementation requires:

- A forward-looking roadmapping process, i.e., relating different policy instruments to each other in a time sequence that helps optimising synergetic effects and minimising unintended negative side-effects so as to outline a roadmap for implementing the mix; and
- Consideration of political processes in polycentric governance systems in order to be able to identify and secure long-term multi-actor support, to monitor processes and adapt the mix in feedback loops over time in a coherent manner (Karoline S. Rogge and Reichardt 2016; del Rio and Howlett 2013; Howlett 2004).

Thus, the concept of policy mixes will challenge political practices and experience. Resulting from political needs, such as existing alliances, election-based tactics, or lacking time or knowledge, policy formulation often leads to so-called policy layering instead of policy mixing in the above sense (Howlett and Rayner 2007). Therefore, political realities, as well as the dynamics and path dependencies of legislative periods, run counter to a strategic and more long-term implementation procedure of policy mixes.

Furthermore, the heuristic concept (cf. Figure 9) encourages – or even necessitates –considering and including scientific assessment results when developing policy mixes (see step 4 in Figure 9). This proves challenging for several reasons: (1) robustly assessing cumulative impacts of policy instruments in a time-dynamic sequential manner is very demanding both in terms of conceptual and computing power (simulation models) of those undertaking the scientific assessment (e.g. Hirschnitz-Garbers and Langsdorf 2016). (2) Linked to that, scientific findings will always come with a degree of uncertainty, which good scientific practice demands being communicated transparently, while policy making typically calls for concrete proposals with (near) certainty (e.g. Persson 2016; Martinuzzi 2016; European Commission 2000; Gollier and Treich 2003). (3) Policy making informed by or based on science needs to follow issues of legitimacy – in particular policy objectives, but also the final choice and design of policy instruments to be implemented in order to achieve the objectives, must be the result of democratic processes and political negotiations (Persson 2016).

(4) Hence, in the final decision making by democratically elected institutions, decision-makers must weigh different sources of knowledge and different options against each other in the context of political and socio-economic feasibility. In order for a policy mix to be successful it should be tailored to a specific problem context. Here, it is important to consider the full range of policy instruments available (incentives, command and control, information and persuasion, infrastructure, enabling), looking not only at their environmental effectiveness, but also at implementation costs for authorities or transaction and compliance costs for addressees as well as at potentially negative unintended side effects on target groups (e.g. issues of competitiveness for industry or regressive effects on lower-income households) because these aspects may raise issues of acceptance and feasibility (Howlett and Rayner 2007; del Rio and Howlett 2013). This necessitates skills and capacities among decision-makers for long-term views on potentially relevant effects, which are often based on uncertain (scientific) knowledge. A prevailing political economy of maximising chances to maintain power from one election term to the next rewards short-termism and a focus on immediate benefits – it discourages long-term thinking with more distant benefits (see e.g. Howlett and Rayner 2007; del Rio and Howlett 2013).

Hence, designing, implementing, and evaluating policy mixes poses a formidable challenge to scientific assessment and even more so to practical implementation in existing policy settings and politics.

In the following section, we describe the approach used in the SimRess policy mix to develop and assess policy mixes for systemic resource policy as well as the challenges encountered and the lessons learnt.

2.4 Policy mixing for systemic resource policy in the SimRess project – approach, challenges and lessons learnt

According to sections 2.1 and 2.2 resource policy needs to be(come) more systemic in nature in order to address the complexity of intertwined drivers for unsustainable resource use and to tackle the wicked environmental problems putting social-ecological systems at risk – therefore, it appears logical to apply systems thinking to address issues of resource efficiency policy (Ekvall et al. 2016; Hirschnitz-Garbers et al. 2016; Hirschnitz-Garbers et al. 2015).

In the context of the SimRess project, the research focus was on national resource policy, but through international value chains and trade flows also embedded into the European and international resource policy context. Hence, despite the system boundaries of the resource policy approach being the national borders, both effects of international trends and policy actions on German resource policy and vice versa were considered in a more systemic way.

Over the course of the SimRess project, we developed three different policy mixes approaches. They differ in the level of detail, on the one hand because of stakeholder feedback in the ongoing national resource policy (in the context of ProgRess II; see BMUB 2016a)) and on the other hand due to the requirements of the simulation model used for their ex-ante assessments. The conceptual development of the policy mixes followed the iterative, multi-step procedure as outlined in the heuristic concept (cf. Figure 9).

Due to the project's nature as a research project, we completed only the iterative steps up to step 4 (undertaking ex-ante assessments) for two of the policy mix approaches developed. According to stakeholder feedback, the other policy mix was considered less relevant in the contemporary resource policy context of ProgRess II so that this was not included in the ex-ante assessments.

We will now describe the process for each of the three policy mix approaches according to the different iterative steps of the heuristic concept. Please note that

a) only one of the policy mix approaches (see section 2.4.3) deviates from the general resource policy objectives and targets set in Germany. Hence, we will elaborate on this general set of policy objectives and targets only in section 2.4.1 and then describe the changed setting in section 2.4.3;
b) the general causal model of the problem situation and the need for systemic resource policy responses is similar for all three policy mix approaches; therefore, we will describe it in detail for the first policy mix approach and only provide complementary thoughts for the other two policy mix approaches where relevant.

2.4.1 A systemic resource policy mix approach tackling key drivers and trends

2.4.1.1 Setting objectives and targets

German resource policy aims at reducing pressures on the environment, boosting competitiveness and growth of the German economy as well as securing existing and creating new jobs (BMUB 2016b). With the scope of natural resources covered by German resource policy under ProgRess II (i.e. the material use of ores, industrial minerals, construction minerals as well as material use of fossil fuels and biotic raw materials) the core quantitative resource policy target is the doubling of Germany's raw material productivity from 1994 to 2020, measured as GDP/DMI_{abiot} (BMUB 2016b).

Although discussed in the scientific and environmental community (e.g. Bringezu and Schütz 2013; Bringezu 2015; Günther and Golde 2015; Schmidt-Bleek 1994; BIO Intelligence Service, Ecology, and SERI 2012; Dittrich et al. 2012), further quantified targets, in particular per capita resource use targets, have not been laid down in official resource policy documents in Germany. Qualitative objectives prevail – they aim at increasing

- Resource efficiency; i.e. maintaining or increasing economic value in terms of GDP, products or services with the same or reduced resource input while reducing environmental impacts (partially related to the concept of eco-efficiency, which puts the value of a product in relation to the environmental impacts caused by the product system, incl. production). Resource efficiency measures the ratio of benefit (economic value) to cost (resource input needed) (BIO Intelligence Service, Ecology, and SERI 2012; Brischke and Spengler 2011);
- Consistency; i.e. replacing finite and non-renewable resources by renewable resources and hence turning resource consumption to resource (re)use. This necessitates that economic activities consequently use environmentally friendly technologies and apply the principle of circularity and closing loops (UBA 2012);
- Decoupling of resource use from economic growth; the term 'decoupling' refers to breaking the link between "environmental bads" (environmental impacts) and "economic goods" (e.g. economic growth, usually measured as GDP) (OECD 2002). According to UNEP (2011), decoupling in the context of resource use has four different dimensions: (1) 'resource decoupling' denotes the delinking of resource use and economic growth, while (2) 'impact decoupling' refers to delinking environmental impacts and economic growth – both dimensions are integrated in the concept of 'double decoupling'. Furthermore, (3) 'relative decoupling' means that environmental impacts or resource use continue to grow, but at a slower rate than economic growth; (4) 'absolute decoupling', in contrast, describes a situation where resource use and/or environmental impacts are stagnating or declining in absolute terms, compared to a base-year. In recent years, political support for absolute decoupling has been waning and, hence, most references to decoupling in policy documents do not specify whether relative or absolute decoupling shall be achieved (e.g. BMUB 2016b);14
- Sufficiency; i.e. reducing the need and demand for resource use through raising awareness for a „right" degree of resource use. This necessitates a simplification towards essentials as well as shifting the focus from consumption and status symbols to immaterial values and a good life (Alcott 2008; Brischke and Spengler 2011). However, ProgRess II does not explicitly mention sufficiency as an objective; it refers to it when listing activities at regional (Länder) level or among civil society organizations, such as Friends of the Earth Germany (BMUB 2016b).

Hence, the focus of this policy mix approach was to contribute to achieving the above quantitative target and the qualitative objectives, albeit to different extent – see section 2.4.1.3.

2.4.1.2 Underlying conceptual causal system model

As outlined in sections 2.1 and 2.2 above, the problem situation of a complex web of drivers for unsustainable resource use and prevailing wicked environmental problems calls for more systemic resource policy (Hirschnitz-Garbers et al. 2016; Ekvall et al. 2016).

In order to identify systemic intervention points for national resource policy to develop the resource policy mix approach, we started by integrating findings from the Causal-Loop-Diagrams (CLDs), that originated from the stakeholder workshops described in section 1.1, and the trend report elaborated in the SimRess project (Langsdorf and Hirschnitz-Garbers 2014). These intervention points encompass both relevant consumption areas (in particular food, housing and mobility; see EEA 2013; Tukker et al. 2006) and different stages of the value chain (from extraction to consumption and after-use). The following exemplary CLDs was elaborated in participatory stakeholder workshop settings for food (Figure 10) (please see also Even though the stakeholder participatory group modelling process was

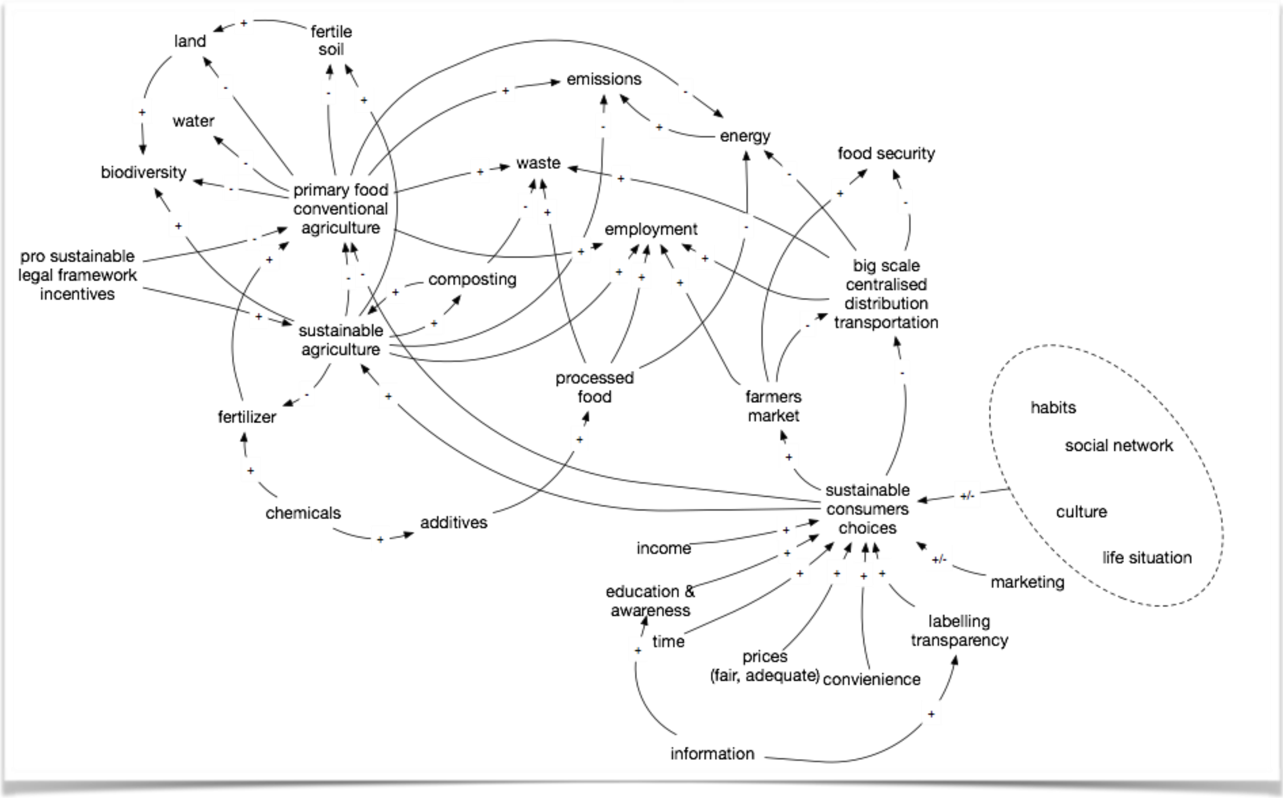
[14] However, the 7th Environment Action Programme explicitly refers to absolute decoupling, e.g. in Priority objective 2: To turn the Union into a resource-efficient, green and competitive low-carbon economy (European Parliament and European Council 2013, No. 29).

terminated after the first two workshops, the SimRess project partners agreed upon continuing with internally organised system science based group modelling workshops.

An internal group modelling workshop was organised with the participation of SimRess project partners and representatives from UBA. The discussions focused on four thematic areas during the workshop: construction/infrastructure, private household consumption, employment and the environmental impacts of resource use in general. **Fehler! Ungültiger Eigenverweis auf Textmarke.**, as an example, shows the causal loop diagram built by the participants following their discussions around private household consumption and its environmental impacts.

Figure 4 Causal Loop Diagram with the theme of private household consumption on p. 30 of this report).

Figure 10: CLD for the consumption area of food (Koca and Sverdrup 2014a, 24)



Source: Authors

Both Even though the stakeholder participatory group modelling process was terminated after the first two workshops, the SimRess project partners agreed upon continuing with internally organised system science based group modelling workshops.

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Figure 4 and Figure 10 show, that in order to foster sustainable resource use in these consumption areas, resource policy intervention needs to focus both on a change of (individual and collective) behaviour (e.g. consumer choices, practices, awareness) as well as on the framework conditions shaping such behaviour (e.g. through infrastructures, regulatory frameworks, products and services at offer) (see also Hirschnitz-Garbers et al. 2015; Defila, Di Giulio, and Kaufmann-Hayoz 2014; Røpke 2009; Shove and Warde 2002).

Furthermore, the different stages of the value chain point to very different actors that systemic resource policy should focus on, for instance businesses and industry for extraction and production as well as private (households and businesses) and public consumers for consumption and after-use (Hirschnitz-Garbers and Langsdorf 2016; UNEP 2011). Figure 8 “Causal loop diagram showing the demand for cars and the production, and the causal linkages between these factors” above (p. 33) links different policy intervention points to causal factors and system elements – this shows that policy interventions should consider the entire range from end-of-pipe solutions to sustainable consumption and production policies (Mont and Dalhammar 2005).

Together with some plausible trends identified in SimRess to have the potential to affect resource use (and resource policy) in the future (Langsdorf and Hirschnitz-Garbers 2014), these systemic intervention points provided the basis to consider and select promising policy instruments for the mix.

2.4.1.3 Selecting promising policy instruments

We undertook a comprehensive review of literature from past and ongoing research projects on resource policy as well as of relevant policy documents to compile an inventory of potentially promising policy instruments to select from for developing the policy mix. Therefore, we considered

a) as policy documents

- Progress I (BMU 2012)
- ProgRess II (BMUB 2016b)
- Climate Action Programme (BMUB 2014)

b) as research projects

- Developing Economic Instruments in Support of Increasing Resource Efficiency (EconRess) – a German research project funded under UFOPLAN, FKZ 3712 93 105 (2013 – 2016)
- Resource Policy (PolRess) – a German research project funded under UFOPLAN, FKZ 3711 93 103 (2012 – 2015)[15]
- Material Efficiency and Resource Conservation (MaRess) – a German research project funded under UFOPLAN, FKZ 3707 93 300 (2007– 2010)[16]
- Dynamic Policy Mixes for absolute decoupling of EU economic growth from resource use and environmental impacts (DYNAMIX) – a European research project funded under FP7 (2012 – 2016)[17]
- Policy Options for a Resource Efficient Europe (POLFREE) –a European research project funded under FP7 (2012 – 2016)[18].

[15] www.ressourcenpolitik.de

[16] http://ressourcen.wupperinst.org/en/home/index.html

[17] http://dynamix-project.eu/

[18] http://polfree.seri.at/

This research yielded an inventory of more than 300 instruments, for which we then described, as much as possible, the instrument types (e.g. regulatory, economic, information-based), the key instrument mechanisms (e.g. providing incentives, limiting market access, raising awareness) and intervention logic in the CLD context (this inventory list is available upon request).

We then categorised the instruments along the above descriptors (type, mechanisms and intervention logic) and identified a short-list of those instruments, which according to information available from the above-mentioned list of policy documents and research projects, appear to have the greatest potential or seem most promising to tackle key drivers, break relevant trends and achieve systemic resource policy objectives. In relation to the most relevant key drivers and trends we tried to identify those instruments that have the potential to counteract

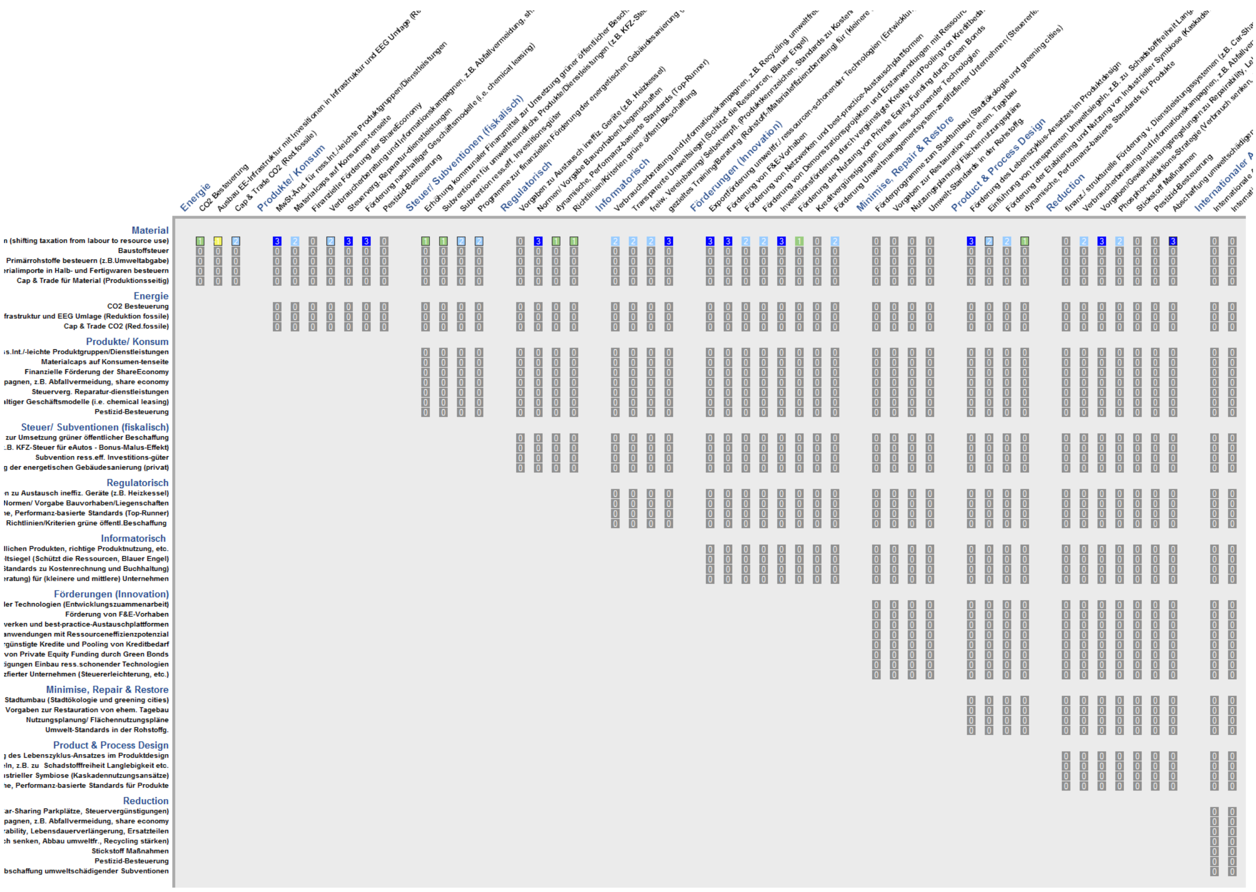
- the proliferation of consumerist lifestyles and social norms;
- increasingly short product and consumption cycles that fuel a linear throw-away mentality;
- path dependencies created by infrastructure design and planning;
- volatile resource prices as well as resource prices not reflecting ecological and social costs.

This short list we then clustered

a) based on CLD invention points along instruments targeting: relative prices; industrial production and business-to-business (B2B) consumption; Household demand and consumption (business-to-consumer, B2C); public demand and consumption (Business-to-government, B2G). This was done with the intention to facilitate later ex-ante assessment via simulation models;
b) according to overarching objective of the instruments: (absolute) reduction of resource use; efficiency gains; minimisation of environmental impacts.

This cluster short-list then constituted the so-called option space (Optionsraum) for selecting different instruments from for the policy mix (see Table 3, Appendix). This option space was created in coordination with EUSG and UBA and was set up using the EIDOS software. From this option space, we developed different policy instrument and tested them for their internal consistency in order to exclude inconsistent mixes, where the instruments combined would suggest trade-offs of conflict of objectives.

Figure 11: Screenshot of the SimRess consistency matrix in EIDOS



Source: eusg/Authors

The terms highlighted in blue font colour denote the clusters; the individual instruments in each cluster are listed below (left hand side) or to the right of the cluster headings (top). In the consistency check, we first assessed in a brainstorming workshop the consistency of each combination of instruments in the consistency matrix (see Figure 11) by assigning values from -3 (not consistent at all) to 3 (very consistent). Then, we used the EIDOS software to compute the overall consistency value of individual instrument combinations selected with a view on promising potential – the higher the overall consistence value, the higher the internal policy instrument mix consistency.

Thus, we developed three different and mutually complementing policy instrument mixes, each with a different focus on desired effects:

1. Policy mix focus: fostering sustainable consumption
2. Policy mix focus: fostering sustainable production
3. Policy mix focus: fostering absolute reduction

1. Policy mix focus: fostering sustainable consumption

This policy mix combines instruments, which aim at (1) fostering behaviour among consumers and at (2) increasing availability of (more) sustainable products and services. (1) Interventions fostering more sustainable consumer choices encompass subsidies for environmentally friendly products and services (lowering purchasing and use prices), introduction of transparent and credible eco-labels, financial support for installing resource saving technologies in the housing sector as well as consumer counselling and information campaigns. (2) Availability of (more) sustainable products and services shall be increased via dynamic, performance-based environmental standards (top-runner concept), financial support for transforming urban planning (e.g. installing separate driving lanes or free parking spaces for car-sharing or electric vehicles) and enhancing the use of life-cycle assessment in product design.

Thus, this policy instrument mix focuses on shifting consumption to sustainable products and services, much less on reducing consumption overall. Potential rebound-effects shall be counteracted by means of market-based instruments, in particular ecological tax reform and a Cap & Trade-System for CO2. In order to minimise burden shifting of negative social and environmental impacts from domestic consumption, additional environmental and social standards shall be proposed for raw material extraction activities.

2. Policy mix focus: fostering sustainable production

This policy instrument mix targets producers and production. In order not to overburden competitiveness of the German industry, this instrument mix centres on an ecological tax reform (shifting taxation from labour to resource use). Economic instruments form the core of this mix, aiming to reward and thus foster sustainable producers. Resource saving and market-access are targeted by a Cap & Trade-System for CO2, dynamic, performance-based environmental standards (top-runner concept) as well as environmental and social standards for raw material extraction activities. These shall be flanked by measures that ease the transition to more sustainable business models, such as subsidies for resource efficient investment goods, financial support for sharing economy business models, provision of resource efficiency advice and skilling as well as financial support for Research & Development (R&D). Furthermore, this mix contains state support for industrial symbiosis and incentives for to invest in product-service-systems. As a strong focus on producers and production may discriminate against the domestic economy in the global market, this policy mix should also include efforts to promote international policy support and international standards to create a level playing field for more resource efficient production.

3. Policy mix focus: fostering absolute reduction

This policy instrument mix is the most ambitious as well as the most radical mix in the current political climate. Alongside a comprehensive ecological tax reform and a Cap & Trade-System for CO2, this mix suggests a Cap & Trade System for Materials on household level. While addressing both consumer and producers, the main impetus lies on changing the economic system via consumer decisions. In order to enable consumers to comply with ambitious instruments, such as the Material Cap, these shall be accompanied by consumer counselling and information campaigns.

Dynamic, performance-based standards for products and services shall continuously enhance product resource efficiency and resource efficient product design. Strict environmental standards for extraction activities shall minimise international environmental impacts of domestic consumption.

Several instruments support businesses in the transformation, in particular subsidies for resource efficient investment goods, but also resource efficiency advice for SMEs and financial support for pilot/demonstration projects.

A brief description (in German only) of the instruments suggested above is available upon request.

2.4.1.4 Undertaking ex-ante assessments

Despite the comprehensive preparation and detailed conceptualisation of the above three policy mix foci, a stakeholder workshop in November 2015 (Fachgespräch UBA) decided not to pursue this approach further in the SimRess project. Instead, with a view on the release of ProgRess II in the first quarter of 2016, it was decided to focus the conceptual development and ex-ante assessment of policy mixes in SimRess on

- A selection of instruments from ProgRess II to show potential effects of these measures (see section 2.4.2 below);
- A mix of policy intervention points, which according to model simulations would contribute to achieving more ambitious, longer-term resource policy targets (significant improvements in resource productivity and reductions in resource use) without putting competitiveness of the German Economy at risk (see section 2.4.3 below).

This decision appeared to be rooted in the current political economy and the attempt to increase policy relevance of the research findings – not only were many of the instruments proposed in the above three policy mix foci deemed politically not feasible in the short-term, but also should the research findings attempt to support the processes of further developing ProgRess II in the years to come.

2.4.2 A resource policy mix approach based on selected ProgRess II policy instruments

2.4.2.1 Setting objectives and targets

For this ProgRess-II-based policy mix the main objectives and targets set include:

- Doubling of Germany's raw material productivity from 1994 to 2020, measured as GDP/$DMI_{a\text{-}biot}$ (BMUB 2016b);
- Increasing resource efficiency;
- Improving Consistency;
- Fostering decoupling of resource use from economic growth.

2.4.2.2 Underlying conceptual causal system model

The theoretical causal model is similar to the one detailed under section 2.4.1.2 above. ProgRess II also builds on the logic of fostering resource efficiency across all stages of the value chain, from extraction through to after-use (BMUB 2016b). This is reflected in the five strategic approaches of ProgRess:

1. Securing a sustainable raw material supply
2. Raising resource efficiency in production
3. Making consumption more resource-efficient
4. Enhancing resource-efficient closed-cycle management
5. Use of cross-cutting instruments

This setting formed the basis for our identification of relevant systemic intervention points, i.e. selecting from the strategic approaches to build the policy mix. Through a series online and telephone exchange sessions with the project officers from UBA, we arrived at a selection of four out of the five strategic approaches (all but No. 4 Enhancing resource-efficient closed-cycle management, because of reasons of the political economy) from which to select instruments for the ProgRess-II-based policy mix.

2.4.2.3 Selecting promising instruments

ProgRess II contains more than 120 instruments (so-called policy approaches) (BMUB 2016b). The exclusion of strategic approach No. 4 reduced this number by some 15 instruments. The series of exchanges with the UBA project officers yielded a list of seven action areas, from which seven corresponding policy approaches were selected to build on for an ex-ante assessment (cf. Table 2):

Table 2: List of selected policy approaches from ProgRess strategic approaches and action areas

Strategic approach	Action area	Policy approaches selected for ex-ante assessment
1. Securing a sustainable raw material supply	1.5 Environment-friendly expansion of material use of regenerative resources	Nature-friendly and environment friendly use of biomass materials
2. Raising resource efficiency in production	2.1 Developing and disseminating resource-efficient production and processing methods	Continuation and expansion of funding programs for material- and energy-efficient technologies and processes
	2.2 Expanding efficiency consulting for companies	Nation-wide expansion of resource efficiency consulting
3. Making consumption more resource-efficient	3.3 Incorporating resource efficiency in product development	Greater support for resource efficiency through standard setting
	3.5 Expanding incentives for better market penetration with resource-efficient products and services	Increased product diversity in the Blue Angel 'protects resources' category
5. Use of cross-cutting instruments	5.1 Resource-efficient neighborhood and building development, construction, refurbishment and use	Funding of research on resource-efficient, integrated solutions for planning, design, construction and refurbishment, incl. initial and further training
	5.2 Resource-efficient infrastructure	Dismantling, where feasible, of obsolete structures and recovery of construction materials for recycling and reuse

2.4.2.4 Undertaking ex-ante assessments

We used the environmentally-extended multi-regional Input-Output model GINFORS, a global dynamic econometric model, to undertake ex-ante assessment of potential effects of the above policy approaches on selected socio-economic and environmental indicators. The process of translating the policy approaches into parameters that the modelling environment can represent (the so-called parametrisation) and key findings are described in Distelkamp and Meyer (2017).

The ex-ante assessment focused on potential impacts of the individual ProgRess-II based instrument proposal. Potential cumulative effects (synergies or trade-offs) were not modeled as the conceptualisation of the policy mix was not tasked with considering roadmapping options of a coherently combined instrument mix.

During a second stakeholder workshop in June 2016 (Fachgespräch UBA) findings for the ProgRess-II-based policy mix were presented and discussed. In the light of these discussions, both the direction and process were outlined for developing a policy mix aimed at contributing to more ambitious, longer-term resource policy targets (significant improvements in resource productivity and reductions in resource use) without putting competitiveness of the German Economy at risk. As the conceptual mechanisms leading to the development of this policy mix differ from those for the previous two, this text will be made the new heading level 2.4.3.

2.4.3 A systemic resource policy mix approach aimed at contributing to more ambitious, longer-term resource policy targets

2.4.3.1 Setting objectives and targets

Going beyond the set of targets and objectives used for the two above policy mixes, during the June 2016 stakeholder workshop (Fachgespräch UBA) we agreed to use the more ambitious, longer-term resource policy targets proposed by Günther and (2015) for this policy mix. They propose

1. Reducing RMC_{abiot} per capita by 30-50% by 2030 compared to 2010; this would translate to an annual reduction in RMC_{abiot} of 2 – 2.5% (Distelkamp 2016).
2. Increasing total resource productivity (GDP+Imports)/RMI_{abiot} by 40-60% by 2030 compared to 2010; this would translate to an annual increase in total resource productivity of at least 2.3% (Distelkamp 2016).

2.4.3.2 Underlying conceptual causal system model

While the general conceptual causal system model developed for the first policy mix (see section 2.4.1 above) also applies to the development of this policy mix, the process used differs significantly. Here, we did not pursue the identification of systemic intervention points to derive potentially promising instruments to then test against their potential effects. In fact, we applied the so-called "reverse engineering" logic in GINFORS, whereby relevant model parameters are changed so that they allow achieving pre-set targets. This process necessitates sound expertise on the part of the modelling experts because in order to guide and structure such an model experimentation procedure they need to be able to infer relevant model parameters from past model simulation experience.

Based on tweaking the demand of resource relevant industries for certain commodities in the context of a functioning world and national economy, the modelling experts identified

- on the one hand those sectors with greatest potential of contributing to the above two resource policy targets;
- and on the other hand the magnitude of changes in demand that these sectors can receive without putting the economy at risk, despite generating winners and losers among existing and emerging industries.

2.4.3.3 Selecting promising instruments

The diversity of sectoral changes enabling target achievement in the model did not allow us identifying concrete policy instruments that could trigger these changes within the remaining time and budget of the project. Therefore, in the SimRess project we could only infer rather aggregated pointers for policy intervention at the coarse level of system transformation through

- Tackling both behaviour and structural changes via
- Ambitious policy that

a) Focuses on reducing use of primary inputs and fostering secondary material use, and
b) Has the courage to address lifestyle changes and structural changes by rewarding change and penalising lacking will for change, while as much as possible mitigating negative effects for losers.

But identifying and suggesting concrete policy approaches and instruments for how this should be tackled warrants more research and stakeholder selection processes beyond the SimRess project.

2.4.3.4 Undertaking ex-ante assessments

The procedure and the results of the reverse engineering policy mix approach undertaken in GINFORS are documented in detail in Distelkamp and Meyer (2017).

2.5 Lessons learnt on policy mixing for systemic resource policy

The SimRess project provided opportunities to test and reflect on the concept of policy mixing for use in resource policy. In this chapter, we would like to draw lessons learnt on key challenges that confronted SimRess as regards the conceptual development and the scientific assessment of the policy mixes in the context of a research project.

2.5.1 Conceptual development of the policy mix approaches

In principle, we could apply the first three iterative steps in the heuristic policy mixing concept (target setting; underlying conceptual causal system model; selecting instruments) for the three SimRess policy mixes described in section 2.4, albeit to a different extent. However, we found the conceptual development of the policy mixes limited

1. by stakeholder and project management decisions not to pursue further the development and assessment of a systemic resource policy mix tackling key drivers and trends (see section 2.4.1). From a scientific point of view, albeit still constituting an instrument mix, this policy mix approach was developed furthest through testing the instruments contained for internal consistency in order to exclude inconsistent mixes, where the instruments combined would suggest trade-offs of conflict of objectives;
2. to a mix of instruments in the resource policy mix based on selected ProgRess II policy instruments (see section 2.4.2). The instruments are only conceptually connected via the logic of intervening at different stages of the value chain: e.g. sustainable raw material supply from biomass; fostering resource efficient production through resource efficiency consulting and funding programs; expanding the offer of resource efficient products via standard setting and Blue Angel labeling. They were neither tested for consistency, nor combined in a time-dynamic sequential manner defining which instrument(s) will come first and for how long and which will come later in what order (so-called 'roadmapping' process);
3. to a reverse engineering based intervention logic of sector changes in a systemic resource policy mix approach aimed at contributing to more ambitious, longer-term resource policy targets (see section 2.4.3), which we could not develop further into explicit policy instrument proposals.

Hence, as one key challenge we encountered the need to integrate input from science and stakeholders into the development of the policy mix approaches. As outlined in section 2.4.1 above, the structured approach chosen for the development of a systemic resource policy mix approach tackling key drivers and trends did not meet sufficient stakeholder interest to be further pursued towards ex-ante assessment. In the political economy we encountered, this resulted in re-orienting the available conceptual and modelling capacities in the SimRess project towards investigating one policy mix approach based consisting of a small selection of ProgRess II instruments (section 2.4.2), which due to the ProgRess II dialogues was believed to receive wider societal and stakeholder support; and another policy mix approach (section 2.4.3) aimed at more ambitious, longer-term resource policy targets sill in need of a wider societal debate on necessities and feasibility.

Owing to the specific capacities of and requests to the SimRess project, we were able to assess only a small fraction of existing and potentially conceivable and promising policy instruments in SimRess. While the stakeholder workshops were instrumental in generating buy-in to SimRess policy mix analyses, they also interfered with the scientific inquiry into policy mixing for a resource efficient Germany in 2050 by narrowing down the assessment of policy mix approaches to instruments already officially proposed in ProgRess II. This finding seems to be generalisable to other research project contexts operating at the science-policy interface (e.g. for the FP7-project DYNAMIX see Hirschnitz-Garbers and Langsdorf 2016) where scientific interest and capacities have to be aligned with policy relevance and the political economy in order to allow for uptake of scientific findings in policy making (Martinuzzi

2016). This maybe disappointing from the perspective of scientific inquiry, but it is essential to keep the necessary dialogue between scientific evidence and policy making open and to help make science become applied in reality. Furthermore, only through such boundary management at the science-policy interface can the democratic legitimacy of (resource) policy making be maintained and undue outsourcing of responsibility on science to provide the silver bullet without any need for political negotiation rejected (Persson 2016; Gollier and Treich 2003; European Commission 2000; Martinuzzi 2016).

In our view, the objectives of the research project as well as the project capacities and the above stakeholder feedback did not allow the policy mixes to be conceptualised as a coherent whole for (theoretical) implementation. Because neither a comprehensive instrument selection and re-design of the mix based on ex-ante assessments, nor a roadmapping towards (theoretical) implementation of the mix could be carried out, the SimRess policy mixes do not represent policy mixes in the comprehensive understanding of Howlett and others (see e.g. Howlett and Rayner 2007; del Rio and Howlett 2013; K.S. Rogge and Reichardt 2013; Karoline S. Rogge and Reichardt 2016). Therefore, we termed them policy mix approaches.

This links to the fact that conceptually developing and assessing policy mixes is very challenging from a scientific perspective – and even more so in the decision-making context of policy making negotiations with often clashing short-term needs and long-term visions.

2.5.2 Scientific assessment of the policy mix approaches

Another key challenge was the scientific, model-based assessment of the policy mix approaches. As outlined above, we could only undertake ex-ante assessment for two policy mix approaches. Here, the quantitative model-based assessment of the policy mixes was confined to

- assessing individual instruments (for the ProgRess-II based policy mix approach) without a view on their potential cumulative effects (synergies or trade-offs from interactions). This was not a matter of lacking parametrisation capacities nor of insufficient computing power, but it was in fact due to stakeholder feedback and project capacities limiting the conceptual development of this policy mix approach;
- assessing potential impacts of changes in the demand of resource-relevant sectors towards target achievement, without translating the causes of such changes to policy instruments. The diversity of sectoral changes enabling target achievement in the model did not allow us identifying concrete policy instruments that could trigger these changes within the remaining time and budget of the project.

Hence, assessing cumulative effects of instrument combinations over time was constrained by the conceptualisations of the policy mixes. But we cannot say whether, and if so to what extent, assessing such conceptualisations could be beyond the capacities of modelling tools (for comparison see also Hirschnitz-Garbers and Langsdorf 2016). While the development of a policy mix as part of a research project can deliver scientific ex-ante assessments relevant for redesigning a policy mix, this process is complicated by (see Hirschnitz-Garbers and Langsdorf 2016):

1. the inherent difficulty of assessing cumulative effectiveness of a mix in contrast to that of the individual instruments; this remains a methodological challenge requiring more research. Furthermore, the specific modelling logic of the GINFORS simulation model used might limit its ability to model some instruments or instrument designs that could lead to systemic changes – assessing this was beyond the research tasks in SimRess and would require further analyses;
2. the logical gap between a scientific ex-ante assessment of a policy mix' potential effects and its actual implementation in real-world contexts, which will inevitably change the nature or design and hence the impacts of the mix through the political processes. Any policy mixing effort will experience several adaptation rounds during its development, refinement, implementation, evaluation

and refinement, which may change the mix fundamentally from what it was initially meant to be based on an(y) initial scientific ex-ante assessment.

Developing consistent and coherent resource policy mixes can contribute to a much more systemic and possibly also a more effective strategy for policy-making. Nonetheless, no scientific policy mix conceptualisation, nor any ex-ante assessment can navigate the political processes, which may impact both on the eventual policy mix design and on its implementation. Hence, the limits in conceptualising policy mixes for implementation in the research context seem also linked to issues of political realities – not only do the constant need for negotiations and often clashing short-term needs and long-term visions complicate policy mix conceptualisation in the decision-making context, but also may the associated skills for policy makers be mismatched with skills and expertise hitherto needed in policy careers.

Looking at potential effects of policy mixes on target groups, including potential synergies and trade-offs between policy mix instruments or policy mix objectives, in a constantly changing context of power relations, relevant actors and possible coalitions makes the concept of policy mixing a very complex and hence very challenging task for policy preparatory and policy makers (del Rio and Howlett 2013; Karoline S. Rogge and Reichardt 2016; Minogue 2002). Adding the need for long-term views and hence for coalition building for implementing long-term policy mix objectives further complicates this process and may make it appear insurmountable – maybe due to current political practices rendering policy mixing a risk for political survival, and having yielded skills unfit for tackling policy mixing.

Therefore, albeit a promising concept to improve systems thinking and long-term views in resource policy, policy mixing is met with formidable challenges, which need to be better understood in order to increase the applicability of policy mixing for systemic resource policy. Further research from organisational theory and political economy may help shed light on circumstances under which such strategic policy-making would be possible and through which skills and actions its feasibility could be strengthened.

3 Main conclusions

System analysis seems well adapted to support forward-looking and systemic resource policy. Thinking in terms of system feedbacks and causal relations between the various factors determining resource use allows policy making to take a wider scope of issues into perspective, which reduces the risk of blind spots. And long-term ex-ante assessments, as aided by SD modelling, enable to look beyond the typical time coverage of simulation models used for policy advice – this can help identifying time delays and feedbacks otherwise undetected, notwithstanding the challenges associated with long-term policy making.

Furthermore, system analysis features means to meaningfully engage stakeholders, through the joint language of CLDs, into understanding a system and in jointly creating solutions in the system in question. Thus, ownership of solutions among various actors can be fostered and wider support be forged for actually realizing systemic action addressing problems identified in a given system.

However, as the SimRess project experience shows, there are many pitfalls that challenge or thwart successful stakeholder participation. Identifying key stakeholders for the system that shall be analysed is crucial to enhance fit between stakeholder interests and the purpose of system analysis – and thus to increase chances that stakeholders will participate. Nonetheless, winning, and in particular maintaining, their participation over a series of GMWs poses a formidable challenge and needs both clear-cut questions for analysis and committing sufficient resources on the side of those organising the GMWs. Furthermore, it demands a great degree of flexibility from GWM organisers in order to gain as much as possible from a GMW series with fluctuating participants. However, potential results of GMWs are worth the effort as they provide a level of detail that often has not been available for system analyses before the workshops and hence provides an important asset.

And yet, using this asset in system analysis necessitates to transparently define how GMW results will further be used in and translated to models set to provide simulation results for integrated system analysis. In the SimRess project context, the cancellation of the external GMWs after the second such workshop created a situation differing from ideal-typical system analysis processes: as stakeholder interest and ownership were waning, the external GMW results were less useful and so the CLDs had to be finalised internally. Hence, the further creation and use of GMW results had only to be coordinated with the project team. This in itself also prove challenging due to the two modelling systems used with different underlying paradigms. In exchange between the two modelling teams the econometric modelling team agreed to an attempt of creating a CLD for a selected part of the GINFORS3 model scope – meant to address concerns of users of modelling findings that some models are a black box. This certainly aided mutual understanding of where and also how much the approaches applied for setting up and defining the model environments differ. It furthermore eased finding a common language and identifying options for exchange of information between the two models (the soft-link created). But it also highlighted that the models differ for good reasons in many aspects – and that the central feature making the SimRess project stand out from other similar research projects is a very valuable, but also difficult endeavour. Hence, more such inter-modeler exchange is needed (see also (Biemann et al. 2017)).

Due to differences in parametrisation procedures, only the GINFORS model could be used to assess the potential effects of policy interventions on resource use. Nonetheless, in the context of applying the policy mixing concept to the SimRess project, a systemic perspective was taken for conceptualising policy mixes – this ensured that short to long-term trends were taken into consideration and that, hence, also the WORLD model findings as regards long-term scarcities were taken into regard for selecting policy instruments in the policy mixes.

The concept of policy mixing as applied appeared to fit well with system analysis as it could build on the CLDs elaborated for identifying generic interventions points and also could respond to systemic drivers and trends partly identified in the GMWs. However, project capacities and stakeholder workshop decisions steered the policy mixing process in a certain direction, which did not allow us undertaking a fully-fledged policy mix design process. While in our view, the policy mixing concept in general perfectly complements system analysis (because as it requires building a causal model and thinking in terms of interactions and feedbacks between different instruments), it is very difficult to apply – in scientific ex-ante assessments, due to of challenges in parametrising and simulating cumulative effects of different instruments sequentially interlinked over time; and even more so in actual policy making as policy making practices, routines and environments are locked into shorter-term thinking and developing skills for long-term coalition building are discouraged. Both aspects can be overcome by more research applying the concept of policy mixing and investigating factors that could enhance policy mixing in policy making practices.

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5 Appendix

Table 3: Snapshot of the option space created for the systemic resource policy mix tackling key drivers and trends (cf. section 2.4.1)

	Reduktion (absolut)			Effizienzsteigerung (bzgl. Wirtschaftsleistung BIP)				Minimierung von Umweltwirkungen		
	Material	Energie	Produkte/Konsum	Steuer/Subvention (fiskalisch)	Regulatorisch	Informatorisch	Förderung (Innovation)	Minimise, Repair & Restore	Product & Process Design	Reduction
Instrumente pro Ansatzpunkt aus Liste Einzelmaßnahmen	Ökosteuerreform (shifting taxation from labour to resource use)	CO2 Besteuerung	MwSt-Änderungen für ressourcenintensive/-leichte Produktgruppen/Dienstleistungen (z.B. MWSt - Bonus-Malus-Effekt, Steuervergünstigung für die Nutzung von Car-Sharing)	Erhöhung kommunaler Finanzmittel zur Umsetzung grüner öffentlicher Beschaffung	Vorgaben zu Austausch ineffizienter Geräte (z.B. Heizkessel)	Verbraucherberatung und Informationskampagnen, z.B. Recycling, umweltfreundlichen Produkten, richtige Produktnutzung, etc.	Exportförderung umweltfreundlicher und ressourcenschonender Technologien (Entwicklungszusammenarbeit im Bereich Ressourceneffizienz)	Förderprogramme zum Stadtumbau (Stadtökologie und greening cities)	Förderung des Lebenszyklus-Ansatzes im Produktdesign	Verbraucherberatung und Informationskampagnen, z.B. Abfallvermeidung, share economy
	Baustoffsteuer	Ausbau EE-Infrastruktur mit Investitionen in Infrastruktur und EEG Umlage (Reduktion fossile)	Materialcaps (& Trade) auf Haushaltsebene	Subventionen für umweltfreundliche Produkte/Dienstleistungen (z.B. KFZ-Steuer für eAutos - Bonus-Malus-Effekt)	Normen und Vorgaben zu öffentlichen Bauvorhaben/Liegenschaften (Leitfaden nachhaltiges Bauen - z.B. Einsatz von nachwachsenden Rohstoffen im Bereich Bauen und Wohnen; energetische Gebäudesanierung)	Einführung von transparenten Umweltsiegeln, z.B. Weiterentwicklung der Kategorie "Schützt die Ressourcen" für Blauen Engel (Verbindung zu Subvention umwelfreundlicher Produkte/Dienstleistungen)	Förderung von F&E-Vorhaben	Vorgaben (in der Bewilligungsphase) zur Restauration von ehem. Tagebau	Einführung von transparenten Umweltsiegeln, z.B. zu Schadstofffreiheit Langlebigkeit etc.	Vorgaben/Gewährleistungsregelungen zu Repairability, Lebensdauerverlängerung, Ersatzteilen
	Primärrohstoffe besteuern (z.B. Umweltabgabe)	Cap & Trade CO2 (Reduktion fossile)	Förderung der Nachfrage von ShareEconomy-Angeboten (finanziell der strukturell, z.B. Car-Sharing Parkplätze, Steuervergünstigung für die Nutzung von Car-Sharing)	Subvention ressourceneffizienter Investitionsgüter (B2B, grüne unternehmerische Beschaffung)	dynamische, Performanz-basierte Standards (Top-Runner)	freiwillig Vereinbarungen und Selbstverpflichtungen (z.B. freiwillige Produktkennzeichnung, Standards zu Kostenrechnung und Buchhaltung)	Förderung von Netzwerken und best-practice-Austauschplattformen	Nutzungsplanung/ Flächennutzungspläne	Förderung der Etablierung und Nutzung von Industrieller Symbiose (Kaskadennutzungsansätze)	Phosphorreduktions-Strategie (in Parametrisierung auf Effizienzsteigerung, Verbrauch reduzieren, Abbau u-freundlicher gestalten und Recycling stärken eingehen - hier fehlen noch konkretere Maßnahmen, z.B. Steuern, F&E, ...)
	Materialimporte in Halb- und Fertigwaren besteuern		Verbraucherberatung und Informationskampagnen, z.B. Abfallvermeidung, share economy	Programme zur finanziellen Förderung der energetischen Gebäudesanierung (privat)	Richtlinien/verbindliche Kriterien für grüne öffentliche Beschaffung	gezieltes Training/Beratung (Rohstoff-/Materialeffizienzberatung) für (kleinere und mittlere) Unternehmen	Förderung von Demonstrationsprojekten und Erstanwendungen mit Ressourceneffizienzpotenzial	Umwelt-Standards in der Rohstoffgewinnung	dynamische, Performanz-basierte Standards für Produkte	Pestizid-Besteuerung
	Cap & Trade für Material (Produktionsseitig)		Steuervergünstigungen für die Inanspruchnahme von Reparaturdienstleistungen				Investitionsförderung durch vergünstigte Kredite und Pooling von Kreditbedarf	Internationale Abkommen/Übereinkommen/Konventionen (u.a. to get the prices right) => Bedarf an Konkretisierung		Abschaffung umweltschädigender Subventionen
	Internationale Abkommen/Übereinkommen/Konventionen (u.a. to get the prices right) => Bedarf an Konkretisierung		Förderung nachhaltiger Geschäftsmodelle der ShareEconomy (i.e. chemical leasing)				Förderung der Nutzung von Private Equity Funding durch Green Bonds	**internationale Maßnahmen der BRD:** Vergabe von Krediten, ggf. Handelsbeschränkungen, bilaterale Abkommen, Hermesbürgschaften		Stickstoff Maßnahmen (Reduktion der Nutzung/Einbringen von Stickstoff, Reduktion Eutrophierung)
	internationale Maßnahmen der BRD: Vergabe von Krediten, ggf. Handelsbeschränkungen, bilaterale Abkommen, Hermesbürgschaften		Pestizid-Besteuerung				Kreditvergünstigungen für Einbau ressourcenschonender Technologien (Wasser- und Energiesparen, smart metering, energetische Gebäudesanierungen)			
							Förderung Umweltmanagementsystem-zertifizierter Unternehmen (z.B. durch Steuererleichterungen oder Besserstellung in öffentlichen Vergabeverfahren durch entsprechende Kriterien)			

Supported under the German Environment Agency's UFOPLAN programme, FKZ: 3712 93 102

Section I 1.1 Fundamental Aspects, Sustainability Strategies and Scenarios, Sustainable Resource Use

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