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Balancing Time-Energy Trade-Offs in Long-Distance Electric Vehicle Driving: The Role of Subjective Appraisals in Multi-Goal Regulation

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ABSTRACT

Multi-goal balancing is a core demand in long-distance electric vehicle (EV) driving, where time and energy objectives are coordinated in a dynamic environment. The present study is grounded in control-loop models of self-regulation, conceptualizing that drivers iteratively compare perceived states to reference values and adjust speed or charging strategies accordingly. Within this regulatory process, effective goal balancing depends on how drivers interpret task-relevant information and translate these appraisals into action. Two determinants are particularly relevant: informational support and subjective competence. Informational support is understood as system- or environment-provided cues that are timely, interpretable, and task-aligned within action-regulation processes. Subjective competence refers to drivers' self-appraisal of their capability to meet task demands, grounded in task knowledge and usable strategies. An online survey of EV drivers (N = 57) assessed Perceived Support of Action Regulation (PSAR), Subjective Range Competence (SRC), and Subjective Goal-Balancing Competence (SGBC). Results showed that both PSAR and SRC were positively associated with SGBC, indicating that perceived informational support and range-related subjective competence systematically co-occur with higher subjective competence to coordinate time and energy goals under constraints. The findings highlight the relevance of driver-centered feedback as regulatory support for managing time-energy trade-offs.

Keywords: Action regulation, Multiple goals, Time-energy trade-offs, Electric mobility, Energy efficiency, Ecodriving

INTRODUCTION

Understanding habitual energy use from a psychological perspective is essential for designing systems, processes, and interactions that advance energy efficiency alongside other core goals in everyday driving (e.g., safety, comfort, time efficiency). In electric vehicle (EV) driving, a key component of the broader shift toward climate-neutral, electrically powered mobility, the coordination of energy efficiency and travel time becomes particularly salient as range, consumption, and charging opportunities are structurally interlinked (Franke & Krems, 2013; Thorhauge et al., 2024; Wang et al., 2024).

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Energy efficiency in EV driving is jointly shaped by technology and driver behavior. Alongside technical advances, operational ecodriving, understood as the adoption of driving strategies that reduce energy consumption, contributes to energy efficiency (Sivak & Schoettle, 2012). On long-distance EV trips, journeys that exceed a vehicle's single-charge range and require at least one charging stop, these strategies explicitly balance time-energy efficiency goals.

In practice, time and energy goals can align. For instance, anticipatory, steady driving lowers consumption and, by reducing the need for charging or shortening charging duration, reduces total travel time, provided time is not constrained by factors such as congestion, queuing at chargers, or other conditions that negate time savings from lower consumption.

Conversely, time-energy conflicts may arise when both objectives are simultaneously pursued: for example, a higher cruising speed may reduce driving time while increasing energy use, potentially necessitating an additional charging stop. However, if either objective is considered irrelevant or if other goals are prioritized, this trade-off does not manifest as a conflict.

Consequently, on long-distance trips, drivers may engage in continuous multi-goal regulation for optimizing goal attainment, reconciling time-energy trade-offs that require ongoing monitoring, foresight, and reprioritization as conditions change. Operationally, drivers can address potential goal conflicts typically by (1) choosing, (2) multitasking, or (3) prioritizing (Kung & Scholer, 2020). Specifically, drivers may (1) choose by committing to one single goal (e.g., prioritizing time efficiency by maintaining a higher cruising speed even if this increases consumption and may require an additional charging stop), (2) multitask by adopting strategies that jointly serve both goals (e.g., selecting a moderate speed that preserves range while maintaining the overall trip time acceptable), or (3) prioritize dynamically by allocating regulatory resources to the goal most threatened under current conditions (i.e., showing the largest perceived discrepancy from its desired state; Carver & Scheier, 2000; Powers, 1973; Schmidt & DeShon, 2007; Schmidt & Dolis, 2009).

In addition to situational trade-offs, individual differences may influence which regulatory strategies drivers tend to favor when balancing time and energy demands. Some drivers tend to prioritize the conservation of battery resources, whereas others place greater weight on timely arrival under comparable conditions. These tendencies motivate examining subjective appraisals that shape how drivers interpret information and regulate time-energy trade-offs.

Separate from person-related tendencies, cognitive biases can distort how drivers judge consumption and efficiency. For example, the Miles-per-Gallon (MPG) illusion, in which equal increases in fuel efficiency are mistaken for equal fuel savings, reflects a tendency to misjudge efficiency improvements (Larrick & Soll, 2008). Recent work further shows biased impressions of energy efficiency when drivers rely on instantaneous consumption displays, leading to systematic overestimation of average consumption (Moll & Franke, 2021). Beyond these cognitive distortions, situational constraints such as time pressure shift decisions toward time-saving rather than energy-saving strategies (Dogan et al., 2011; Franke et al., 2017; Allison et al., 2021). While the present study does not examine these mechanisms directly, they indicate that the interpretation and use of task-relevant information can vary substantially, underscoring the value of examining subjective appraisals that shape how drivers interpret state information, perceive discrepancies, and select strategies in time-energy regulation.

All these dynamics of multi-goal regulation in EV driving can be modeled using control theoretic conceptualizations of user behavior (Powers, 1973). Control theory characterizes self-regulation (i.e., action regulation) as an iterative, discrepancy-reducing feedback loop (Carver & Scheier, 2000): In the driving context, individuals monitor their current state via an input function, compare it to internal reference values, and adjust behavior via an output function (Fuller, 2011; Summala, 2007).

Within this control loop, effective regulation relies on how state information (i.e., current state of charge, charger availability) is interpreted relative to reference values (i.e., desired arrival time or consumption target) and how those appraisals are translated into action (i.e., adjusting cruising speed, selecting a charging stop and target state of charge). When multiple goals (i.e., minimizing total travel time while limiting energy use and charging time requirements) are regarded as relevant, drivers must monitor more than one reference value, increasing the complexity of regulation because discrepancies may arise across goal-related reference values at once. Hence, a key question is which factors support this regulatory process in EV driving.

In the present study, we focus on two particularly interesting variables, namely (a) perceived informational support (i.e., having fit-for-purpose cues at the moment of need) and (b) subjective competence (i.e., feeling capable of meeting the current demands).

(a) Fundamentally, informational support refers to system- and environment-provided cues that are timely, interpretable, and aligned with the driver's current state within action-regulation processes. Such cues improve regulation in all three control loop functions: (1) state estimation (input function) by improving access to and comprehension of task-relevant state information (e.g., current state of charge, consumption, charger availability); (2) discrepancy evaluation and reference calibration (reference value / comparator function) by combining discrepancy feedback with forecast information (e.g., updated arrival-time or state-of-charge forecasts) to support situation-specific adjustment of goal-related reference values and acceptable thresholds; and (3) strategy selection and implementation (output function) by enhancing situation awareness and presenting actionable options (e.g., viable charging or route alternatives with constraints and consequences made explicit), thereby facilitating the selection and implementation of an appropriate course of action.

Over time, such support may foster more predictable time-energy expectations and strategic adjustment; from a usability perspective, it supports effectiveness and efficiency and can sustain action confidence (ISO 9241-11:2018; International Organization for Standardization, 2018). In sum, informational support constitutes one regulatory resource that can facilitate effective action regulation on long-distance EV trips (Moll et al., 2025).

Complementing informational support, (b) subjective competence is conceptualized as a subjective appraisal of a driver's capability under current demands, rather than as objective performance metrics. Consistent with the task-capability interface model (Fuller, 2005), effective self-regulation depends on the match between situational demands and perceived capability, with domain-level subjective competence, grounded in task knowledge and a repertoire of strategies for managing EV-relevant requirements such as range management and time-energy trade-offs, providing the backdrop that stabilizes attention, effort, and strategy selection under constraint (Fuller, 2011). Subjective competence is thus closely linked to self-efficacy and manageability appraisals that shape engagement and regulation (Bandura, 1977; Lazarus & Folkman, 1984). These considerations indicate that drivers rely on multiple subjective regulatory resources when navigating time-energy trade-offs, which motivates examining how such appraisals relate to one another within a shared task context.

Building on this perspective, the present study examines multi-goal regulation in EV driving via three subjective appraisal constructs: (1) Perceived Support of Action Regulation (PSAR), (2) Subjective Range Competence (SRC), and (3) Subjective Goal-Balancing Competence (SGBC). (1) PSAR indexes drivers' perceived regulatory usefulness of available informational support, i.e., whether cues are experienced as effective and efficient to use (ISO, 2018) and appropriately matched to the ongoing stage of goal-directed processing (Parasuraman et al., 2000; Wickens & Carswell, 2021). (2) SRC captures subjective competence to estimate remaining range, plan charging, and manage battery resources on long-distance trips; prior work indicates domain-adjacent coherence for SRC with allied outcomes such as lower everyday range stress and greater comfortable range (Franke et al., 2016). (3) SGBC is the self-assessed ability to weigh and reconcile the competing goals of time efficiency and energy efficiency in long-distance EV context, capturing drivers' understanding of time-energy interdependencies, their subjective ability to estimate arrival-time and energy-consumption consequences of different strategies, and the effort involved in coordinating these goals under varying conditions. Accordingly, understanding which factors support this regulatory process becomes central for explaining variability in time-energy regulation.

Building on control-theoretic (Powers, 1973; Carver & Scheier, 2000) and task-capability interface perspectives (Fuller, 2005, 2011) and given that EV driving involves multi-goal regulation, coordinating time and energy under situational constraints, we derive two correlational hypotheses:

H1: PSAR is positively associated with SGBC. Higher perceived stage-appropriate informational support co-occurs with higher SGBC (ISO, 2018; Parasuraman et al., 2000; Wickens & Carswell, 2021).

H2: SRC is positively associated with SGBC. Higher range-related competence co-occurs with higher SGBC (Franke et al., 2016).

In sum, we conceptualize long-distance EV driving as a regulation task in which informational support and subjective competence function as key resources; accordingly, we test whether PSAR and SRC co-occur with SGBC.

METHOD

Participants

Participants for the online LimeSurvey questionnaire (LimeSurvey GmbH, 2012) were recruited through two German-language EV forums and personal networks. Eligibility required being at least 18 years old, having completed at least one long-distance EV trip including a charging stop, and sufficient German language proficiency (minimum B2 level). Participants provided informed consent prior to participation. Upon full questionnaire completion, participants received €5 via bank transfer. Of the 106 total responses, 57 met predefined quality criteria (complete data and a minimum processing time of at least 12 minutes) and were retained for analysis.

As demographics, age and gender (53 male, 3 female, 1 not reported) were recorded. EV experience was indexed by cumulative electrically driven kilometers and range utilization by the lowest state of charge (SOC) ever reported upon arrival at a charging stop. Table 1 summarizes these sample characteristics and additional descriptive indicators.

For descriptive purposes only, the personality trait Affinity for Technology Interaction (ATI; general tendency to actively engage with and explore technological systems; 9-item scale; Franke et al., 2019) was assessed but not included in hypothesis tests. Responses were provided on a 6-point Likert scale ranging from 1 (completely disagree) to 6 (completely agree). Given the study context, the sample likely reflects a comparatively high level of technology affinity, as the mean ATI score exceeded values reported in prior research (Franke et al., 2019).

Table 1: Participant characteristics and experience.

Variable	*M*	*SD*	*P25*	*P50*	*P75*	*α*
Age (years)	52.77	12.26	44.00	55.00	60.00	-
EV experience (total km)	99450	92801	32000	70337	140000	-
Range utilization (lowest SOC, %)	2.72	3.04	1.00	2.00	3.00	-
Affinity for Technology Interaction (ATI)	4.97	0.74	4.67	5.11	5.44	.88

Note. SOC = State of charge, P25 = 25th percentile; P50 = 50th percentile; P75 = 75th percentile; α = Cronbach's alpha; *N* = 57.

Measures

The present study assessed three subjective appraisal constructs central to multi-goal regulation under constraint:

Perceived Support of Action Regulation (PSAR) assesses the extent to which the information available to drivers is experienced as enabling effective regulation in EV use. The 15-item scale, developed by Moll et al. (2025), integrates two complementary perspectives: (a) a usability perspective aligned with ISO 9241-11, indexing perceived effectiveness and efficiency (ISO, 2018), and, beyond the ISO dimensions, action confidence as a satisfaction-adjacent sense of perceived control; (b) an action-regulation perspective grounded in human information-processing models, indexing perceived support across the stages of information acquisition, information analysis, decision selection, and action implementation (Parasuraman et al., 2000; Wickens & Carswell, 2021). To anchor judgments in practice, participants in the original survey underlying the present analysis first listed the vehicle- and environment-based cues they used to balance time and energy, then completed the PSAR items with those cues in mind. Higher scores denote stronger perceived support of the task context under study, i.e. cues are experienced as timely, interpretable, and stage-appropriate for managing time-energy trade-offs. Lower PSAR values, by contrast, indicate informational gaps or ambiguity.

Subjective Range Competence (SRC) captures drivers' self-assessed ability to manage range-related constraints, specifically, to estimate remaining range, plan charging, and manage battery resources. Conceptually, SRC reflects confidence in predicting remaining range and subjective control over range-relevant constraints; higher scores indicate greater subjective competence. In the present study, SRC was measured with a seven-item scale adapted and extended by Stattkus-Fortange et al. (2026) from the original instrument by Franke et al. (2013, 2016).

Subjective Goal-Balancing Competence (SGBC) indexes the self-assessed ability to weigh and integrate time-energy goals during long-distance EV driving. As no established measure was available, the SGBC scale was newly developed for the original data collection with eight items specifically targeting the regulation of time and energy efficiency in long-distance EV trip contexts. The items cover three facets: (a) understanding and strategically managing time-energy interdependencies, (b) accuracy in estimating travel time and consumption consequences of different driving strategies, and (c) perceived effort required for balancing. Higher scores indicate greater SGBC. The scale reflects drivers' subjective competence relevant for managing time-energy trade-offs under varying situational demands.

Across SGBC, SRC, and PSAR, responses were provided on a 6-point Likert scale ranging from 1 (completely disagree) to 6 (completely agree), and scale scores were computed as item means.

RESULTS

Descriptive statistics for the variables included in the hypotheses are summarized in Table 2.

Among the 57 long-distance EV drivers with complete data, Perceived Support of Action Regulation (PSAR) demonstrated a positive association with Subjective Goal-Balancing Competence (SGBC), $r = .52$, $t(55) = 4.51$, $p < .001$, 95% CI [.29, .68]. The confidence interval indicates a non-trivial association ranging from small-to-moderate to large effect sizes. This result is consistent with hypothesis H1 that higher perceived regulatory support co-occurs with higher subjective competence to balance multiple goals. Subjective Range Competence (SRC) was similarly associated with SGBC, $r = .61$, $t(55) = 5.71$, $p < .001$, 95% CI [.42, .75]. The confidence interval lies entirely within the moderate-to-large range. The result is consistent with hypothesis H2 that confidence in managing range constraints co-occurs with a higher subjective competence to coordinate multiple goals under situational demands. All association tests are undirected (correlational) and do not imply causal ordering.

Table 2: Descriptive statistics of key variables.

Variable	*M*	*SD*	*P25*	*P50*	*P75*	*α*
PSAR	4.87	0.47	4.53	4.93	5.33	.97
SRC	4.66	0.65	4.29	4.86	5.14	.82
SGBC	4.75	0.73	4.25	4.88	5.25	.90

Note. PSAR = Perceived Support of Action Regulation; SRC = Subjective Range Competence; SGBC = Subjective Goal-Balancing Competence; P25 = 25th percentile; P50 = 50th percentile; P75 = 75th percentile; α = Cronbach's alpha; *N* = 57.

DISCUSSION

Summary and Implications

The objective of the present study was to examine whether Perceived Support of Action Regulation (PSAR) and Subjective Range Competence (SRC) co-occur with Subjective Goal-Balancing Competence (SGBC) in long-distance EV driving. Consistent with H1, PSAR was positively associated with SGBC. Consistent with H2, SRC was likewise positively associated with SGBC.

In a context where managing time-energy trade-offs may be a recurring consideration, these associations suggest that drivers who perceive the available time-energy-related information as usable and stage-appropriate, and who appraise themselves as capable of managing range-related constraints, also report higher confidence in coordinating time and energy goals.

These associations are also consistent with the control-theoretic view in which effective regulation is conceptualized to depend on readily accessible, well-structured cues that support state estimation, reference calibration, and strategy selection (Carver & Scheier, 2000; Powers, 1973) and with perspectives emphasizing the role of perceived capability under varying task demands (Bandura, 1977; Fuller, 2005, 2011).

From a usability standpoint, as defined by ISO 9241-11 (ISO, 2018), the association between the PSAR total score and SGBC underscores the relevance of driver-centered information that is experienced as supporting effective and efficient goal pursuit, as well as sustaining action confidence (a satisfaction-adjacent sense of perceived control beyond the ISO dimensions), when coordinating time-energy trade-offs.

Similarly, the association between SRC and SGBC aligns with prior findings linking range-related subjective competence to more confident, lower-stress range management (Franke et al., 2016).

In the present correlational design, this co-occurrence may reflect shared appraisals of demand-capability fit and the perceived regulatory usefulness of available information; for example, when the consequences of small strategy adjustments (e.g., speed changes affecting consumption and charging needs) are experienced as clear and usable, drivers may report higher PSAR alongside higher SRC and SGBC.

Overall, the pattern supports viewing PSAR and SRC as subjective regulatory resources that systematically co-occur with SGBC, providing a starting point for more differentiated, stage-resolved and cross-context analyses in future work.

Limitations

The present study examined undirected associations in a sample of experienced EV drivers; generalizability to less experienced drivers or novices remains unclear, as they may face different informational demands and report different competence appraisals. Given the correlational design, the associations in this sample do not indicate causal relationships and should be interpreted as co-occurrences that may reflect differences in how task demands and the perceived regulatory usefulness of available information are appraised. Measures were self-report scales; while appropriate for capturing subjective appraisals central to action regulation, they do not provide behavioral or performance-based evidence. Analyses were conducted at the total scale level, subdimension-level diagnostics for PSAR were not examined (e.g., perceived support of information acquisition, information analysis, decision selection, and action implementation). This limits conclusions about which information-processing stages are most strongly associated with SGBC and reduces the specificity of design-relevant implications. In addition, PSAR captures perceived support from the vehicle- and environment-based cues each participant reported using; participants did not evaluate a standardized set of informational cues or interface features. As the referenced cues likely differed across drivers, the data do not permit inferences about which specific information elements or design properties drive the associations. Future work could assess PSAR under standardized information conditions to link stage-specific support more specifically to SGBC.

Outlook

Two conceptual extensions could provide potential further contributions. Future work could (1) adopt a stage-resolved perspective on perceived informational support by leveraging the information-processing stages embedded in PSAR and (2) extend the subjective-competence perspective beyond range-related competence in long-distance EV driving, examining whether competence appraisals generalize across adjacent self-regulatory contexts.

(1) A stage-resolved approach could differentiate perceived informational support by information-processing stages (as captured by PSAR) and examine whether support at specific stages is more closely associated with SGBC. For example, in the information-analysis stage, future work could compare different feedback formats that make time-energy interdependencies

more transparent (e.g., how small speed adjustments affect consumption and subsequent charging requirements) and examine whether these are particularly associated with SGBC. During decision selection, different option-presentation approaches (e.g., limited charging alternatives with consequences made explicit, potentially reducing cognitive effort) could be contrasted to examine whether perceived support of decision selection is more closely associated with SGBC. Moreover, a stage-differentiated use of PSAR can inform more design-specific hypotheses about which kinds of support are most helpful at which stages of multi-goal regulation.

(2) The perspective on subjective competence could be broadened beyond the on-trip range domain by examining whether subjective competencies correlate across different contexts, building on established work on SRC in EV driving (Franke et al., 2013, 2016). Examples include (a) the closely related field of mobile-device energy management, which focuses on ensuring the continuous availability of a smartphone under conditions of limited battery capacity and involves analogous appraisal-adjustment cycles and multi-goal regulation (Franke & Krems, 2013). Earlier battery-use research (Rahmati & Zhong, 2009) could be revisited from a subjective-competence perspective. (b) Another use case is household energy management in EV-owning homes. Although non-mobile and broader in scope, it involves multi-goal regulation, forecasting and weighing time-energy trade-offs, and adapting strategies under constraints (Kaviani et al., 2025). Examining relationships between SRC and context-adjacent subjective competence appraisals in such domains would help clarify whether subjective competence generalizes across contexts or remains domain-specific, informing whether to emphasize cross-context regulatory resources or domain-tailored support.

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